MONITOR - CTA
☐ Final Report

Urban Mass Transportation Demonstration Project

Project No. IL-06-0010 / DOT Contract No. H-1016

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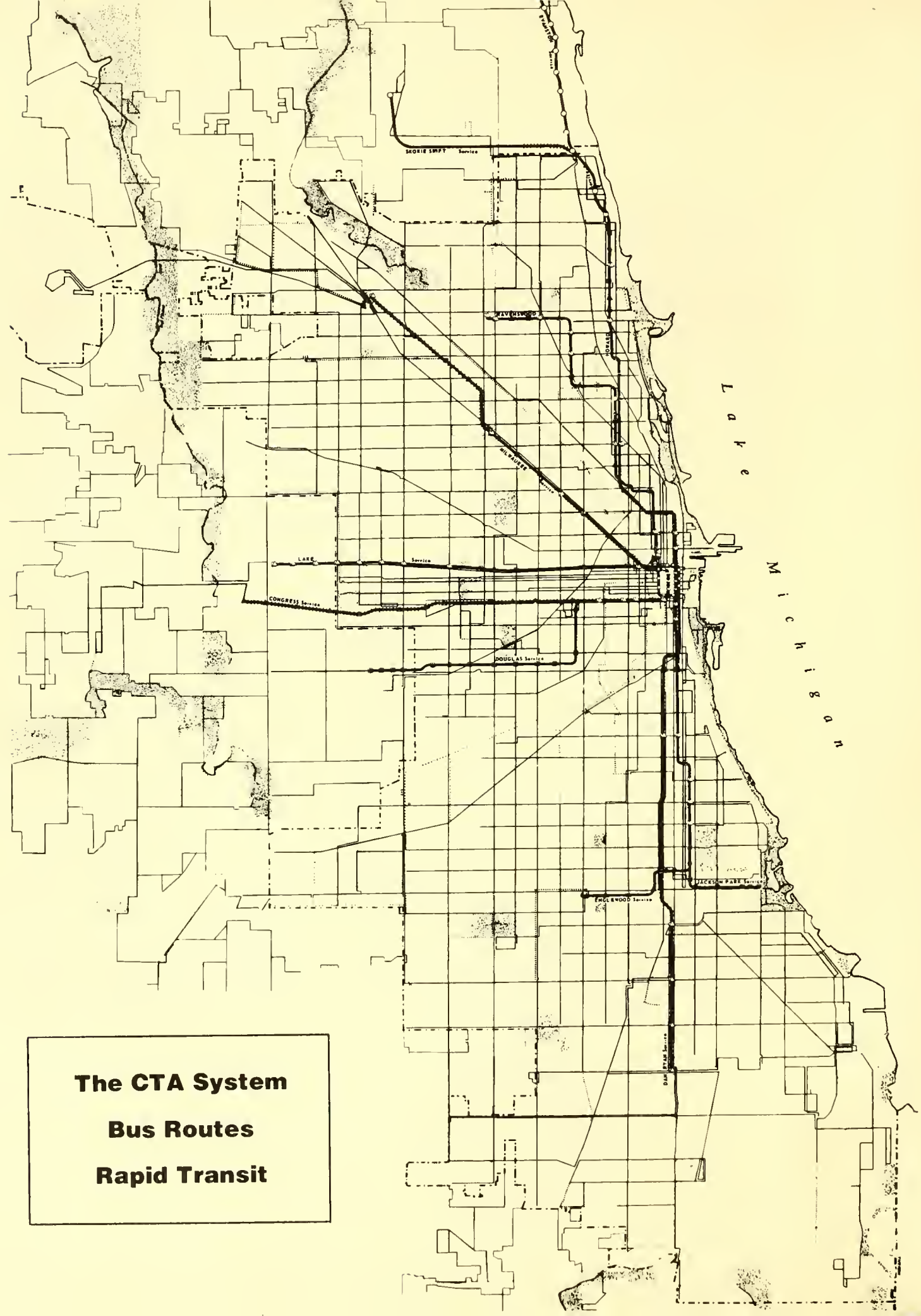

The CTA System

Bus Routes

Rapid Transit

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16. Abstract

This monitoring system was implemented to test the practicability of centralized automatic schedule adherence checking, the effectiveness of a clandestine alarm aboard a transit vehicle and the possibility that such an automated system would allow significant improvement in radio channel utilization.

The evaluation was performed by collecting data pertinent to the system's performance (i.e. accuracy and reliability) in specially designed experiments. The operational aspect was evaluated by collecting data before and after implementation.

The results of the evaluation indicate an excellent potential for increased management information. Although the system performance was adversely affected by poor reliability of the initial equipment aboard the buses, it was shown that this system can maintain schedule adherence at least as well as the present methods, accurately locate a vehicle in an emergency and provide the information capacity of twice as many conventional voice radio channels.

From these results it is concluded that this system is a good investment. Acceptable reliability is assured in future equipment through the technological developments that have taken place since the project was undertaken. Simultaneous modifications in software based on experience with this pilot installation can assure the greatly expanded usefulness of the system.

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MONITOR-CTA FINAL REPORT

AN URBAN MASS TRANSPORTATION DEMONSTRATION PROJECT STUDY OF AUTOMATIC VEHICLE MONITORING

Final report to The U.S. Department of Transportation (DOT) on Mass Transportation Demonstration Project-No. IL-06-0010/DOT Contract No. H-1016

Prepared by:
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The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

TABLE OF CONTENTS

Summary 1

Chapter I BACKGROUND 7
SCHEDULING 8
Service need forecasts 8
The headway sheet 9
Labor planning 10
Supervisor's guide 13

OPERATIONS 14
Dynamic instability 14
Driver responsibility 14
Supervision 14
Service restoration 16
Supervisor cost squeeze 18

AVM HISTORY 19
Chicago's first AVM 19
Rapid transit 19
Bus 20
Lessons from early experiments 20
Other systems 21
CTA accumulates AVM experience 22
The computer 22

DEVELOPMENT OF THE MONITOR PROJECT 23
Object of vehicle monitoring 23
Performance requirements 24
Additional features 25
Area 25
Contract award 27

METHOD OF TEST 27
Schedule adherence 27
The equipment 27

Chapter II ENGINEERING 29
SYSTEM CONSIDERED 30
General discussion 30

MONITOR CTA - THE SYSTEM SELECTED 34
Location aspect 35
Alarm aspect 36
Voice operation 36
Extended capability 36

EQUIPMENT FUNCTIONAL DESCRIPTION 37
Bus location hardware 37
Alarm hardware 42
Voice hardware 43
Satellite receiver voting system 45
Extended capability 46

SYSTEM DESIGN DESCRIPTION 47
Electronic signposts 47
Bus radio 50
Base stations 57
Communication control center 61
Computer interface cabinet 62
Computer hardware 63
Computer software system description 64

Chapter III OPERATIONS 69
SCHEDULE CHECKING 70
Elements of Monitor 71
Bus interrogation cycle 71
Display options 72

Achievement of goals confirmed 72
Goals can be broadened 73
Harnessing Monitor's potential 73
'Debugging' hardware 73

MONITOR ALARM 74
Alarm sequence 74
Experience with the alarm 75
Debugging the alarm 76

VOICE COMMUNICATIONS 77
Features 77
Call procedure 78
Problems with voice radio 78

EMPLOYEE ORIENTATION 79
Training 79
Bus drivers 80
Repair staff 80
Dispatchers 80

Chapter IV MAINTENANCE 81
COMMUNICATIONS 82
The console 82
Programmed analysis 82
Program improvements 82

THE COMPUTER 83

Chapter V EVALUATION 85
ORIGINAL GOAL 86

TESTING 87
Signpost range 87
Location accuracy 88
Communication reliability 90
System reply rate 92
System accuracy 92
Schedule and headway adherence 94
Conclusion 96

EQUIPMENT RELIABILITY 96

COST EVALUATION 101
Voice radio 101
Location system 101
Conclusion 102

FREQUENCY CONVERSION 103
Voice frequencies 103
Data frequencies 103
Signpost location frequencies 104
Radio frequency interference 104
Final system 104

PUBLIC RELATIONS 105

Chapter VI COSTS 107

SYSTEM COST 108

CAPITAL INVESTMENT 108

FINAL PROJECT COST 109

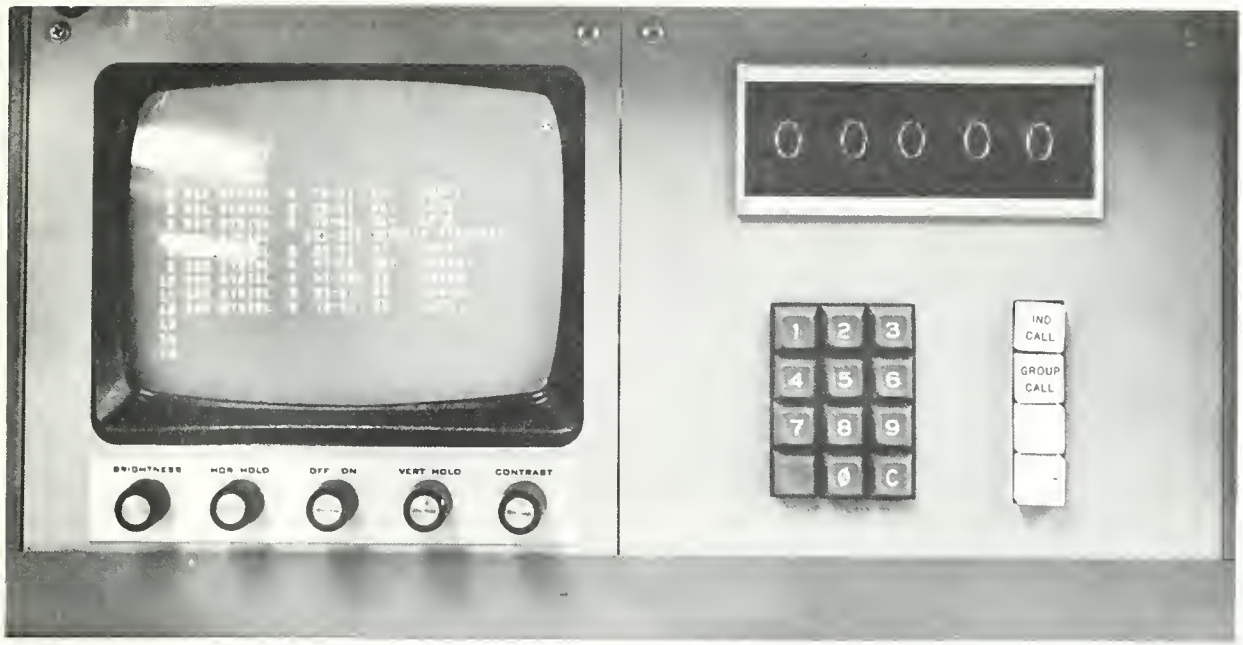
COST OF MONITOR FOR 100% OF CTA 110

Chapter VII THE FUTURE 111
THREE PHASE EXPANSION PROGRAM 112
Phase I - Equip all buses 112
Phase II - Equip all routes 113
Phase I and II - Concurrent CTA efforts 113
Phase III - Total fleet monitoring 113

SUMMARY

Purpose

- To determine the benefits to be derived from an automatic schedule adherence checking system by an urban transit system.
- To evaluate the application of a "display by exception" system (where only those buses operating beyond specified schedule tolerances would be reported by a computer controlled system).
- To study the application of a covert emergency alarm system where the bus driver could secretly signal for help in the event of a robbery or some other serious incident on board his bus.
- To study computer analysis of daily operations as a means to enable faster pinpointing of schedule adherence problems thereby enabling prompt correction of difficulties.
- To determine if high speed digital data alarm and automatic location systems would provide better utilization of radio frequencies than a conventional two way voice radio system.
- To determine if an automatic vehicle monitoring system could result in more effective use of personnel, and more efficient utilization of buses.



BACKGROUND

Since their inception, mass transit operations have strived to insure that the schedules they have produced are followed. When a system's vehicles fail to adhere to their assigned schedules, the result is inconvenience for passengers and increased cost for the operator.

Unfortunately, today the fight to improve schedule adherence on bus lines is an uphill battle. The automobile's stranglehold on our city streets and the resulting traffic congestion has made it increasingly difficult for transit operators to keep their buses "on time".

Until recently, transit operators were unable to muster the resources to cope with the problem. A mass transit operation was often like a huge corporation with, in some cases, thousands of branch offices (buses) without so much as a phone line connecting them with the transit system's management. The unpredictable nature of the urban traffic environment complicated the situation by making it difficult at times for a transit system's management to even know where its branches were.

Yet, perhaps more than in any other business, there is a need for the transit operation to have its branches located where its customers are. To insure that the system meets the needs of its riders, some form of control is needed over schedule adherence performance.

Traditionally, that control has been applied by representatives of the management (supervisors) stationed in the field. Their job has been both to observe the performance of the system and to take remedial action to minimize the effects of disruptions.

A great deal of supervisory manpower is required to adequately monitor a system's performance with anywhere from hundreds to thousands of buses traveling over a city's hundreds of miles of streets.

Today, as traffic problems have grown, so has the need for supervisory manpower. Yet, coincidentally, as auto congestion has increased, so have labor costs making the addition of a desirable number of supervisors prohibitively expensive.

Transit operators have sought to solve the dilemma through the application of technology. The first attempts at automatic vehicle monitoring (AVM) involved simple (by today's standards) electro-mechanical systems to record the passing of vehicles. The equipment did provide a means for manage-

ment to observe a transit system's performance from a centralized location.

Two-way voice radio was installed on the buses of a number of transit companies as soon as it became practical. The radio provided the missing "phone line" communication between the transit operation's management and its "mobile offices," however, deriving information about schedule adherence was tedious and time consuming.

Though the early systems proved that AVM could be useful, their applications were limited by a number of factors:

--They were expensive and the transit industry as a whole did not have the resources to fully develop them.

--In the case of AVM systems there was difficulty in presenting the information they developed on schedule adherence in a usable form. The bulk of the data generated was insignificant (concerning on-time buses), as a result significant data (concerning off-schedule buses) was difficult to evaluate.

--The numbers of radio channels required by a large transit operation could be difficult to "squeeze" into the already crowded radio spectrum.

The Chicago Transit Authority, based on its experience with early AVM systems, concluded that such technology could and should be perfected. A rise in urban crime added to the CTA's interest in AVM, in that such a system could serve as a channel for emergency alarm messages from buses.

The interest in AVM was recognized by the Urban Mass Transportation Administration which in March of 1968 provided CTA with a demonstration grant to test an AVM system. The system to be evaluated in the Monitor-CTA demonstration project was to provide for automatic checking of schedule adherence, improved radio channel utilization, two-way voice radio communication and a clandestine emergency alarm feature.

THE SYSTEM CHOSEN

Equipment for the system (120 low-powered location reference transmitters known as signposts) was installed on 60 routes. Five hundred CTA buses were outfitted with Monitor radios. The routes and the buses chosen so as to provide coverage of all CTA's Owl runs (those buses operating between 12 a.m. and 5 a.m.) Owl runs were selected to maximize the benefits to be derived from the system's silent alarm feature.

A computer is an integral part of the system. The computer is utilized to control all the automatic functions of the system. It is also used to evaluate incoming data on schedule adherence and sort out significant information (essentially which buses are late or early) for the attention of a central dispatcher.

The contract for the construction of the system went to the low bidder, Motorola Communications and Electronics, Inc. with a bid of $1,339,350. The bid included a two-year rental of the computer and two years of maintenance.

THE EVALUATION

The evaluation of the system was divided into two areas: hardware and operational performance. The operations area included schedule adherence tests before and after Monitor. The hardware analysis included tests of signpost range, communications (data) reliability, time accuracy, location accuracy and equipment reliability.

Data for the evaluation of Monitor-CTA was developed in tests conducted by the Transportation Systems Center of the U. S. Department of Transportation and CTA. The majority of the tests were conducted during the summer of 1972.

Results and conclusions drawn from these tests are amply documented in the body of this report; in brief, however, the tests indicated:

--Monitor is capable of performing at least as well as conventional supervisory forces at gathering schedule adherence data.

--The system's excellent potential for generating increased management information makes it an excellent investment from a purely financial point of view.

--A provision for high-speed digital data transmission of location information aids in maximizing the radio channel usage of the system.

--The system performed satisfactorily with the exception of a problem with poor equipment reliability. Care should be taken in the development of specifications for such equipment to insure better dependability.

--There is the possibility of improvements in schedule adherence by using the Monitor as a command and control system.

CONCLUSIONS

We feel that during the demonstration project only a small portion of the system's potential was utilized. Experience with the system enabled us to see that Monitor need not only be an information gathering device for a conventional supervisory force, but that it could itself be used for dynamic command and control.

As an information gathering device, Monitor proved effective. Based on its proven capability and its potential, CTA recommends that a three-phase program be undertaken to equip the entire CTA route structure and fleet with Monitor. Future expansion should allow for the development of the system's dynamic control capability.

CHAPTER I
BACKGROUND

Automated vehicle monitoring (AVM) is not a new concept to the Chicago Transit Authority. Thirty-eight years ago Chicago witnessed its first experiment with such a system.

In the years since then CTA has collected more operational experience with AVM than any other transit system in the country. Monitor-CTA represents the merging of those years of experience with computer age technology.

This chapter traces the development of the Monitor-CTA system from early streetcar headway recording experiments to the writing of specifications for today's computer controlled system.

Also included in the chapter are basic descriptions of CTA's current operating and scheduling procedures. The reader might find these sections useful in understanding the demands of current operations that make AVM so important to the health of today's urban transit systems.

SCHEDULING

The number of buses operated on a CTA route is based on the anticipated volume of passengers at a given time. It is the function of the Schedule Department to forecast the passenger volume, develop schedules to meet the passengers' needs, and then to match operators and equipment with the schedules.

Service need forecasts

Scientific method and "rule of thumb" judgments are employed by scheduling to develop passenger volume predictions. Before scheduling can begin work, a clear statistical history of the ridership habits of a route must be available.

Traffic checkers are the source of most statistical data about a route. An extensive history is kept of their findings on each bus line over a period of years. Current data is developed by actually counting passengers at peak loading points (Fig. 1).

The interval between buses during any given time period is determined by the rate of passenger flow at the peak load points. As the buses are of fixed capacities, it is a question of dividing the capacity of a bus into the amount of passengers expected to board along a route to determine the number of vehicles needed. When the need is determined, the buses are spaced as even as practicable through the time period. The amount of time between buses is known as the headway.

Through experience the schedule makers have developed rule of thumb guidelines to help them analyze raw statistical data. For example, it has been determined that during the same time period normal weekday riding volume can vary as much as 15 percent on any route. As a result a $\pm$ 15 percent margin is applied to the results of traffic counts. The technique prevents possible overloads on fixed capacity buses. Another safety against overloads is built in by calculating each bus's maximum load at 90 percent of its actual capacity.

Predicting the service needs of a route is more complicated than simply adding and dividing. Since the schedules are reviewed only four times a year,

Passenger loading on sample line, eastbound at point E

RUN NUMBER	BUS NUMBER	SCHEDULED	ACTUAL	PASSENGER LOAD
805	3240	730½	730	67
832	3280	734½	735	78
807	3249	737½	737½	75
833	3241	741½	741	79
809	3251	744½	745	78
835	3289	748	748½	82
808	3239	751½	752½	76
827	3244	754½	755	72
811	3279	757½	758	79
834	3252	800½	800½	76

Figure 1

each prediction has to hold true for a few months time. Conditions can be expected to change during those periods as the ridership level is a function of the season, the day, and, of course, the time of day.

Seasonal influences have to be considered each time traffic predictions are made. Just how much of a factor the time of year is on the traffic volume of any given line is determined by reviewing a line's history.

Weekdays, Saturday and Sunday all have distinctive ridership patterns that must be allowed for in projecting ridership. Separate traffic counts are made for all three "types" of days.

The time of day has an effect on the traffic volume. Weekday morning and evening rush hours are the most obvious manifestations of the time factor.

For planning purposes the week day is divided into eight time periods. Traffic counts are used to determine the level service offered during the rush hours while the service offered during other periods is largely based on predetermined policy. For example, "Owl" lines are served as a matter of policy with 1/2 hour headways (Fig. 2).

Daily headway changes

Direction Inbound Period	Interval	Average Ratio of Passengers to Vehicle Seats
5:00 AM to 6:45 AM	10 minute interval	50 to 100%
6:45 AM to 8:45 AM	3 to 6 minute interval	120 to 150%
8:45 AM to 9:45 AM	8 minute interval	100 to 110%
9:45 AM to 2:30 PM	10 minute interval	50 to 100%
Direction Outbound		
1:00 PM to 3:00 PM	10 minute interval	50 to 100%
3:00 PM to 4:00 PM	8 minute interval	100 to 110%
4:00 PM to 6:00 PM	3 to 6 minute interval	120 to 150%
6:00 PM to 8:30 PM	8 minute interval	100 to 110%
8:30 PM to 11:00 PM	10 minute interval	50 to 100%
Between 11:00 PM and 1:00 AM 4:00 AM and 5:00 AM	Policy interval 15 minutes	10 to 60%
Between 1:00 AM and 4:00 AM	Policy interval 30 minutes	5 to 60%

Figure 2

The headway sheet

When the peak load points have been established the schedule maker constructs the headway sheet. The real operating environment of the bus must now be taken into consideration so the vehicles can be scheduled to pass the peak points at the appropriate times with adequate frequency.

Data to determine the necessary time allowances for the operating environment is gathered by traffic checkers riding the vehicles and checking the time consumed moving as a function of passengers and traffic. Repetitive surveys of conditions form a body of statistical data which enables scheduling to accurately anticipate operating conditions (Fig. 3).

When the schedule maker knows the amount of time it will take a bus to get from terminal A to peak loading point B, and he has calculated the necessary interval at which buses will have to pass point B during a given period to accommodate the anticipated traffic, he can schedule the trips necessary. The term trip refers to the schedule plan for a vehicle to go from one end of the line to the other.

Sample line eastbound time allowances

Points	6:35 AM to 7:15 AM	7:30 AM to 9:00 AM	9:30 AM to 12:15 PM	12:25 PM to 3:00 PM	3:20 PM to 5:00 PM	6:45 PM to 12:01 AM
A to B	7	6	6	6	6½	6
B to C	5	4½	3½	4	5½	4
C to D	6	6	5	5½	6½	4½
D to E	12½	12	11	11	12½	10½
E to F	8	8	6	7	7½	6
F to G	7	6	6	6	9	5
G to H	6½	7	6½	6½	7	4½
Total	52	49½	44	46	54½	40½

Figure 3

All the trips are linked or coupled into what is called a train. The train represents the work of one bus from the time it pulls out of the garage to the time it returns (Fig. 4). The trips are coupled together so the bus can make a logical series of round trips on a route.

Allowance for various operational parameters must be built into the trains. Time to recover from delays is built into the coupling time. The "recovery time," usually about 10-15 percent of the round trip time, insures that a delay on one trip does not carry over into the next trip.

Other factors which must be considered are the operating capabilities of a bus as to fuel supply, mechanical limitations and cleanliness of the vehicle. The coupling determines when buses pull out of or pull into garages.

Changing headway requirements throughout the day constitute another factor which must be built into scheduling of trains. Obviously fewer buses are required for longer headways; therefore, some buses that are on the street during rush hours have to be scheduled to return to their garages during off peak hours. On a sample line the buses in service at key times of the day are:

AM rush	-	30	buses
Midday Base	-	15	buses
PM rush	-	34	buses
Evening	-	13	buses
Owl	-	3	buses

Labor planning

The final and most complicated step in scheduling is to translate the trains into the work of operators. In almost every instance trade-offs must be made between management's desire to provide a given level of service at the lowest possible cost and a series of negotiated union contract stipulations. Some of the rules concern:

- Report and "ready" time.
- Travel time to or from distant relief points.
- Maximum length of work time without meal provision.
- Maximum spread from first "start" to last "finish."
- Maximum day's pay.
- Overtime penalties for over standard day.
- Spread premiums for excess spread time.
- Premiums for work after given times of day.
- Percent of "straight" runs.

The Scheduling Department, in an effort to control costs, must balance contract requirements with the following management goals:

- Maximization of productivity:
  Drivers should be on duty only when there is work to be done. Therefore, the split shift is used, where drivers work only rush hour periods, to make sure all their work hours are productive and not consumed in lengthy non-rush hour layover periods.

Garage	A Leave	H Arrive	H Leave	A Arrive	A Leave	H Arrive	H Leave	A Arrive	A Leave	H Arrive	H Leave	A Arrive	A Leave	H Arrive	H Leave
620					635	727	732	812½	820	909½	914½	957½ IN GARAGE			1030
448	503½	542½	547	624	638	730	735	815½	825	914½	919½	1002½	1010	1054	1100 ETC.
454	509	552	557	634	641	733	738	818½ IN GARAGE			851				
629					644	736	741	821½	831	920½	925½	1008½	1020	1104	1110 ETC.
632					647	739	744	824½	837	926½	931½	1014½ IN GARAGE			1034
459	514	558	603	641	650	742	747	827½ IN GARAGE			900				
638					653	745	750	830½ IN GARAGE			1003				
642					657	749	754	834½	843	932½	937½	1020½	1030	1114	1120 ETC.

Couplings

Figure 4

Train No.	Work Portions	Hours 1st	Hours 2nd	Total Hours	Allowed	Total	Spread Premium	Under Time	Over Time	Pay Hours
2-8	448 to RW 956½ RE 1036 to RW 137	509	301	810	26	836			18	8.9
3-2	454 to 851 RW 956½ to RW 117	357	321	718	32	750		10		8.0
6-4	459 to 900 RW 1002½ to RW 127	401	325	726	32	758		2		8.0
1-2	620 to 1030 RW 117 to 520	410	403	813	20	833	40		16	9.5
4-4	629 to RW 1002½ RW 127 to 600	334	433	807	20	827	56		13	9.6
5-8	632 to 1034 RW 127 to 540	402	403	805	20	825	44		12	9.3
7	638 to 1003									
8	657 to RE 1036									

Run sheet showing breakdown of pay hours per train **Figure 5**

-Minimize premium time:
A premium is paid to all split shift operators who do not finish all their working day within 10 hours from their initial start. The premium is assessed at a time and half rate for each hour past 10 hours. For example, if an operator works from 6:00 A.M. to 10:00 A.M. and then from 4:00 P.M. to 8:00 P.M. he will draw nine hours of pay for eight hours of labor.
-Minimize employment:
Employ the least number of operators to keep overhead costs such as salary, insurance, vacation and sick pay at a minimum.

It can be seen that a number of the parameters that must be considered are contradictions to one another. The complicated process of trading off labor's requirements with management's desired ends, demands the attention of a very skilled individual. It is one of many aspects of scheduling that has defied computer programming (Fig. 5).

Supervisor's guide

The final product of the tradeoffs for each driver is the run. The run is a complete schedule of one man's daily activity, including all his departures, arrivals, reliefs, pull-ins, waiting time and lunches. Each run is assigned a run number.

All the runs required to service a single route from a station are organized into a schedule package or supervisors guide (Fig. 6). The guide includes a list of checkpoints along the route which each bus is supposed to pass at scheduled times to maintain proper headways. The checkpoints are known as timepoints.

Page from supervisor's guide

NO.6-1 EB WEEKDAY 79TH STREET #79

RUN	79 KIL	WES LP	ASH	HAL	WEN	COT GR	STO ISL	LV LK FRT	
431		722*	28	35	40	47	52	807	
416	712*	26	31*	38*	43*	50*	55*	810*	#
412	716	29*	35	42	47	54	59	813*	
409	719*	33	38*	45*	50*	57*	02*	816*	#
413	723	36*	42	49	54	01	06	820*	
404	726*	40	45*	52*	57*	04*	09*	824*	#
414	730	43*	49	56	01	08	13	828	
402		745*	51	58	03 04		79-PERRY	806	#
401	734	47*	53	00	05	12	17	831*	#
420	738*	52	57*	04*	09*	16*	21*	836	
406		754*	00	07	12 13		79-PERRY	815	#
417	743	56*	02	09	14	21	26	840*	#
415		759*	05	12	17 18		79-PERRY	820	#
418	747*	01	06*	13*	18*	25*	30*	845	
419	752	05*	11	18	23	30	35	849*	
405		808*	14	21	26 27		79-PERRY	829	#
422	757	10*	16	23	27*	34*	39	854*	#
421	802*	16	21*	28	32*	39*	44	859*	
408		818*	24	30*	35 36		79-PERRY	839	#
424	808	21	26*	33	37*	44*	49	904*	#
407		824*	30	36*	41 42		79-PERRY	844	#

Figure 6

OPERATIONS

Two groups of CTA personnel are directly responsible for seeing that the schedules are kept, the operators and the supervisors. They battle daily with a host of events which might cause buses to deviate from schedule.

With the intensive service (headways at some points are as little as a minute) operated by CTA, a bus just a few minutes off schedule can lead to serious service interruptions. Though the schedule of necessity is based on average conditions, drivers will testify "average" conditions seldom exist in the real operating environment.

On the street the bus is subjected to a variety of factors which tend to force it off its assigned schedule. Traffic congestion, snow, or perhaps heavier than normal passenger traffic can contribute to schedule instability. Any delay in the operation of a bus allowed to go uncorrected can mushroom into more lengthy delays affecting a number of buses on the same route.

Dynamic instability

The escalating process, which plagues virtually every major mass transit property, is known as "dynamic instability." This instability is inherent in high density transit line operations. A well known symptom of the problem, seen by far too many passengers, is the long wait for a bus followed by the arrival of three or four buses bunched together (Illus. 1).

The basis for the instability is the way in which headways are necessarily determined. The spacing between buses is established as a function of passenger volume and time. Any deviation from the assigned time line causes the variation in the number of passengers carried by a bus. Any change in the amount of passengers carried affects the vehicle's time performance (Illus. 2).

Driver responsibility

The initial responsibility for seeing to it that a bus does remain on schedule rests with the driver. He is encouraged to adhere to schedules as closely as possible. The great majority of the operators quickly accept the idea of running on time and routinely attempt to provide the dependable headways CTA's patrons want.

For those drivers who might not accept the importance of maintaining a schedule for its own sake, there are factors which encourage them to adhere to the time line.

-A late bus picks up more people; therefore, the driver has more work to do.

-Disciplinary sanctions from CTA's supervisory force are invoked if a driver runs through timepoints ahead of schedule.

The best policy for any of the drivers obviously is to try and keep his bus on schedule, but there are situations when the best intentions of the driver cannot be depended upon to maintain adequate headways.

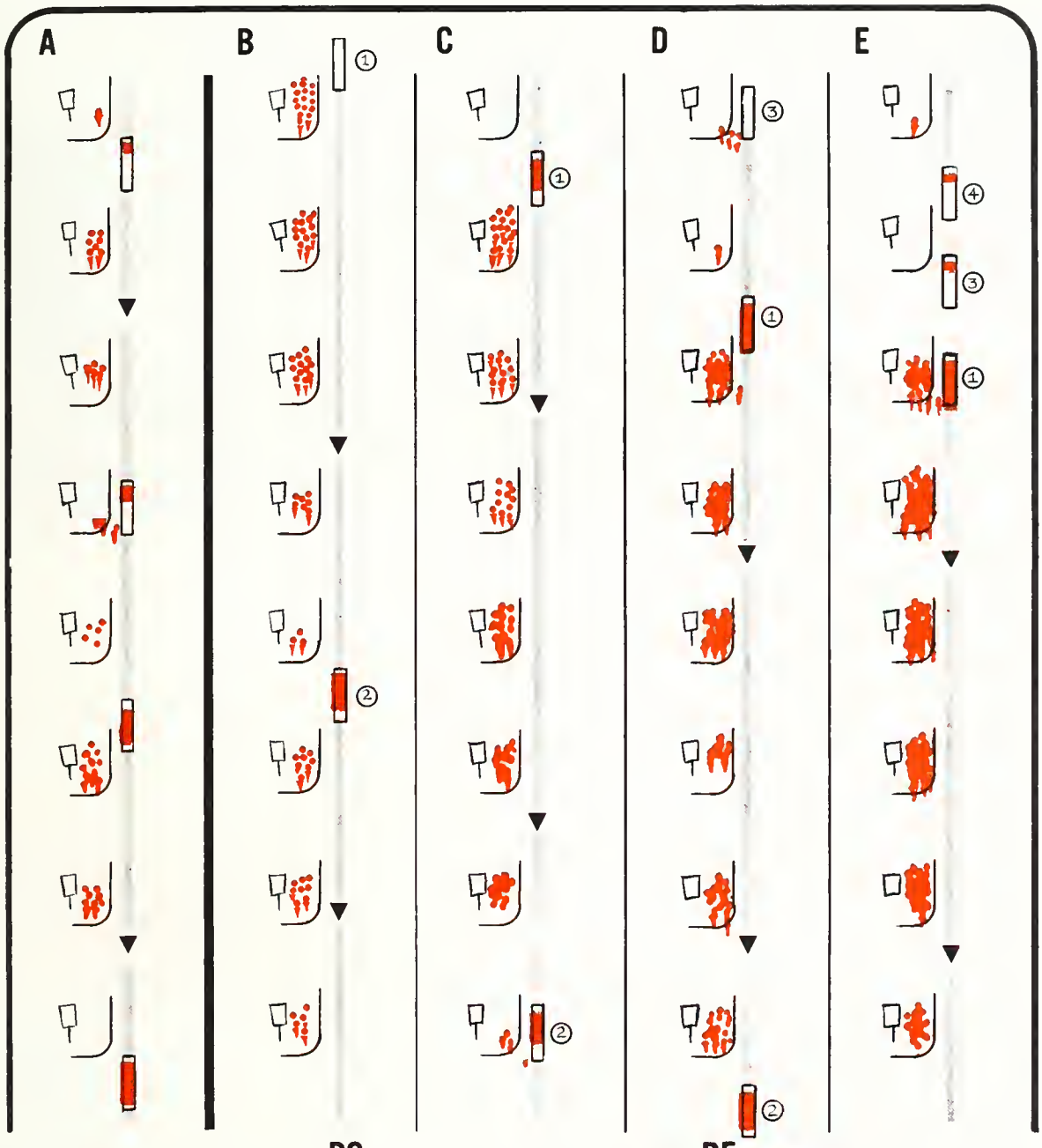
Supervision

From the moment a run leaves its garage it is under the command of Operations Supervision. The supervisory force has the responsibility to monitor bus operations, evaluate real time performance and take whatever remedial action necessary to insure good service.

Information on the system's performance is developed by three sources:

1. Bus drivers phoning in at telephone report points (usually at the end of a line) or calling in with en route emergency reports.
2. Pointmen, actually stationary supervisors, reporting by phone from strategic timepoints on schedule adherence (Illus. 3).

Dynamic instability



A

Ideal headway maintenance: Buses are evenly spaced, as a result they all pick up approximately equal loads of passengers at each stop.

BC

A headway maintenance problem develops: Bus 1 is delayed. A gap develops in Section B and continues to develop in Section C. Larger crowds accumulate at each stop ahead of Bus 1 because of the greater amount of time between Buses 1 and 2.

DE

Dynamic instability becomes a factor. Larger crowds require that Bus 1 spends more loading time at each stop, therefore Bus 1 falls further behind schedule. Bus 3 (on schedule) shortens the gap with Bus 1. In Section D, Bus 1 is so late as to force Bus 3 to be late. Bus 4, with little work to do, catches up with the delayed buses and "bunching" develops.

Illustration 1

'Bunching' is a symptom of dynamic instability

Illustration 2

3. Mobile supervisors who observe line conditions throughout the system (Illus. 4).

The three groups of men are linked together through the dispatcher located at CTA headquarters (Illus. 5). It is his responsibility to coordinate the efforts of all the operating personnel. He is connected to the mobile supervisors by radio and has the authority to dispatch them where necessary.

Problems in the operation of a route are evaluated by on-the-scene supervisors. In some cases the supervisor may be the pointman at a timepoint but more often he is the mobile supervisor who is called upon to review a situation.

The mobile supervisor may be acting on his own immediate observation or he may have been dispatched to the scene by radio. For example, if a driver called the dispatcher to report difficulty maintaining the schedule, the dispatcher would contact a mobile supervisor and send him to assist the driver.

The goal of the supervisory force is to provide both a control over the operations of the system and to minimize the effects of unavoidable disruption of service.

Control is provided by the supervisors authority to recommend disciplinary action against bus drivers violating operating rules. The rules cover not only matters of safety and courtesy but some are concerned with schedule adherence. Supervisors have the authority to "write up" any driver running ahead of schedule though actual disciplinary measures are left to the employee's Station Superintendent. As the driver knows his schedule adherence may be checked at any timepoint by either a mobile supervisor or a pointman, he is encouraged to keep on schedule.

Service restoration

For those operational disturbances which the driver cannot control, e.g. traffic conditions, mechanical difficulties, the supervisor has the responsibility of maintaining as close to normal service as possible. As mentioned previously the most important element of CTA's intensive service is the headway, therefore most service restoration techniques are designed to maintain even headways.

There are a number of basic techniques used to correct any service disruptions.

Spreading or closing the interval involves holding back buses ahead of the delayed bus to minimize the service gap, sending a bus out from a terminal ahead of schedule in anticipation of a delay or rescheduling the buses on a line to divide headways evenly in the event vehicles are missing from service.

Placing the follower ahead requires the supervisor to direct the following bus to pass a delayed bus, thus helping to prevent the delay from growing.

The fill-in is used when there is a gap in headways. A supervisor directs a driver from an intersecting bus route to fill in the gap and leave his line.

Rerouting is necessary when a normal route is blocked.

The switchback is used when the recovery time at the end of a line is less than the delay time. The driver is directed to turn around before he reaches the end of the line and fall back into the schedule in the opposite direction (Illus. 6).

Minor in route repairs can sometimes be made by a supervisor to get a bus back into service.

Trading a defective bus with either a bus ordered out from a garage or one about to pull in allows a supervisor the option of keeping an operator working.

The relief is directed to pull-out bus if the run to be relieved is running so late that it will be unable to reach the outer terminal on time.

Extra trips may be called for when a relief driver fails to show up, severe weather conditions seriously disrupt service, or it is necessary to substitute buses for rapid transit in an emergency.

Shuttle services are established when an unavoidable blockage develops.

Delayed buses are run non-stop if a bus encounters a long delay. Occasionally a different routing is used to speed up the recovery.

Before the supervisor takes any remedial action he must consider a number of factors. His responsibility is first to the passenger, therefore, he tries to trade-off the negative effects of the cure with the possible benefits of service restoration. For example, on a rainy night it would be undesirable to

Pointmen 'Monitor' the on time performance of CTA buses

Illustration 3

direct a bus delayed a few minutes to pass up waiting passengers to correct for a delay.

The supervisor must be sure there is enough supervisory manpower to undertake certain corrective measures. Some delay solutions require the efforts of more than one man. For example, holding back buses to close an interval requires that one supervisor be at the delayed bus and another be stationed down the line to hold back the leading buses.

Supervisor cost squeeze

Because of a chronic lack of supervisory manpower it is often difficult if not impossible to apply the ideal amount of control or proper type of remedial action to operations. The lack of supervisors is not by choice but of economic necessity.

Since the Authority's creation in 1947 the ratio of supervisors to operated mileage has deteriorated. A brutal cost squeeze has lead to a 50 percent reduction in the size of the supervisory force since 1952 when the CTA employed 400 mobile and stationary supervisors to 208 today.

Mobile supervisors operate from radio equipped vehicles.

Illustration 4

Central radio dispatcher

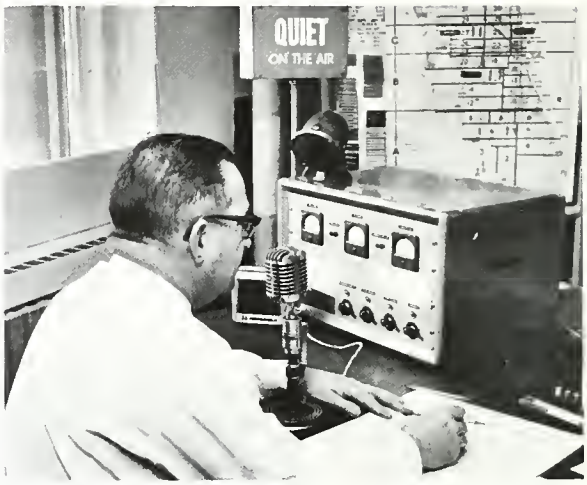


Illustration 5

The result of the lower level of supervision has been an increase in the seriousness and number of service disruptions. With increasing traffic congestions the likelihood of delays occurring has increased dramatically. At the same time the force to counteract disruptions has been reduced.

All the techniques of service restoration previously mentioned require manpower. Manpower is needed not only to carry out the actual corrective measures but more to provide enough real time data to draw an accurate picture of the system's condition at any given moment.

During rush hour it is up to 95 men to keep track of 2,350 buses operating on 135 routes. With the exception of 20 pointmen (whose primary responsibility is schedule adherence checking) most are busy with remedial activities throughout the rush period. They do not have the time to observe the performance of the system as a whole.

Most current supervisory decisions have to be made within something of a vacuum. It is not always possible for the supervisor to see what effects his decision might have on the rest of the system. Therefore, the decisions frequently are not as effective as they might be.

With conventional supervisory techniques there is only one solution to the problem, add more manpower. But faced with a cost squeeze which requires either the elimination of bus drivers and the resulting decline of service or reducing the level of supervision there has been no choice but to choose the latter.

Schematic diagram of a switch back

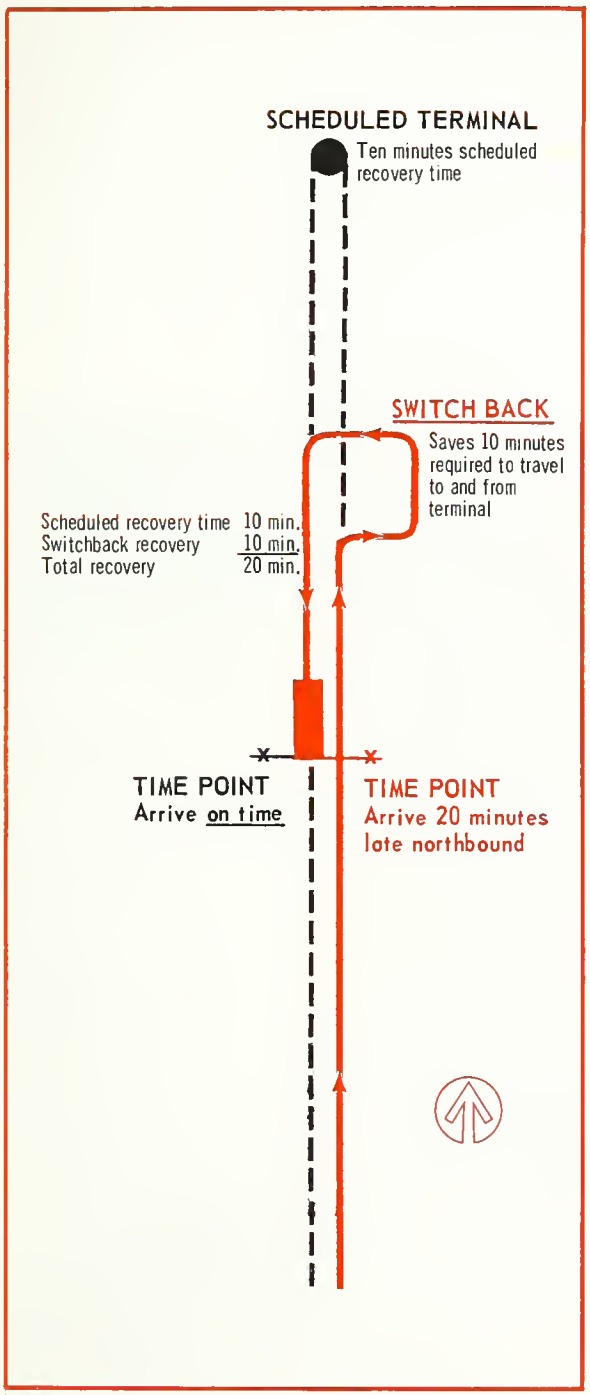

SCHEDULED TERMINAL
Ten minutes scheduled recovery time
SWITCH BACK
Saves 10 minutes required to travel to and from terminal
Scheduled recovery time 10 min.
Switchback recovery 10 min.
Total recovery 20 min.
TIME POINT
Arrive on time
TIME POINT
Arrive 20 minutes late northbound

Illustration 6

AVM HISTORY

Streetcars dominated the transit picture before World War II, therefore early AVM development was tailored to the trolley. Though the headway maintenance problems encountered with those railbound systems were less complicated than the ones facing current bus operations, what was learned then has contributed to the development of today's AVM system.

Chicago's first AVM

Chicago Surface Lines first experimented with an automatic headway recording device in 1935. Recording units were placed at strategic check points. Each time a streetcar passed the point, a mark was made on a timing tape in the unit. The device was activated by the streetcar's trolley passing between two insulated clips suspended from the trolley wire.

Each day the tapes from the headway recorders were collected for evaluation. If a repetitive headway problem was observed, field supervisors could be dispatched to take remedial action, but of course not until the next day.

It was the "next day" aspect of the system that limited its usefulness. The information collected by the device could not be used to deal with delays as they occurred. One could see what went wrong yesterday but not what was happening now. Consequently the system was eventually abandoned.

Rapid transit

In the late 1940s the headway recorder concept was revised and modified to make it a real time supervisory monitoring system for the Authority's rapid transit lines where the reserve pair capacity of the system's line wire telephone network could be utilized for data transmission.

Sample of rapid transit headway recording tape

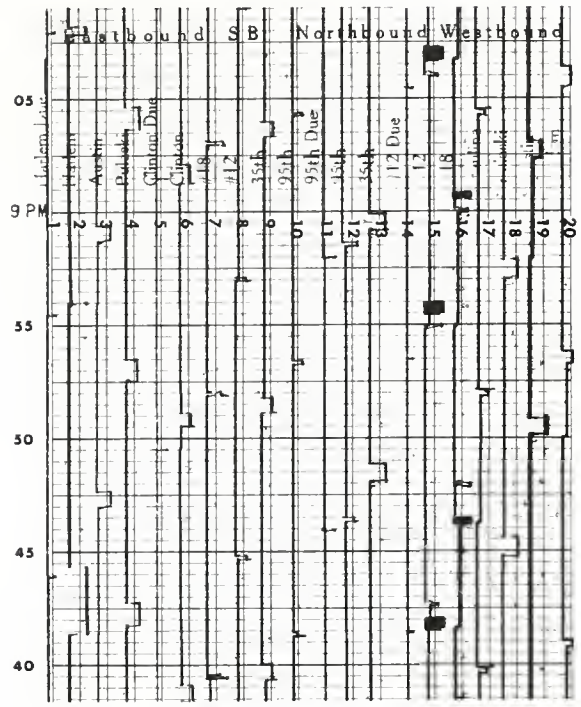


Illustration 7

A train passing over an isolated track section was recorded by headway recorders in a central line supervisor's office. Other spare telephone pairs were put to work for voice communication and dispatching signal control impulses (Illus. 7).

Bus

On the surface system where buses were replacing streetcars supervisory problems grew, even though the newer mode was more flexible in its operation than the railbound system had been. The trouble was that gains in vehicle adaptability were being offset by street congestion resulting from a massive increase in automobile ownership.

The success achieved with centralized supervision on the rapid transit system encouraged experimentation in the area of bus supervision. Vehicle monitoring was instituted on several trolley bus lines.

Passing buses were recorded by trolley contactor devices not significantly different from those of the streetcar days. The contact points were installed at the intersections of bus and rapid transit lines where the impulses could be relayed over the rapid transit telephone system. The blips were recorded by spare pens on the rapid transit system's recorders in the line supervision office (Illus. 8).

A method of record passing motor buses was included in the testing. The buses were equipped with a unique low powered (with a few hundred foot range) radio transmitter (Illus. 9). As one of the equipped vehicles passed a timepoint, a wayside radio receiver would sense the passing bus and relay the information over rapid transit phone lines to the line supervisor's office.

Lessons from early experiments

Experience with the system showed that AVM could be a useful supervisory tool, but its perfection and expansion was limited by the inadequacy of the existing technology.

However, some important lessons for future AVM development were learned from the system.

1. An automatic method to identify vehicles was needed. A dispatcher reviewing the recording charts knew that a bus had passed a timepoint, but he did not know which bus, or in the case of the motor bus, he did not know which direction.
2. Improvements could be made in the information display. With the early system the dispatcher had to sort through a large amount of insignificant data (reports of on time buses) on the recording chart to find the significant information (reports of late or early buses) upon which supervisory action was based.

It was obvious that before the system was expanded to report from the hundreds of timepoints necessary to cover the entire CTA operation (the pilot project reported five timepoints) a method

would have to be developed to adequately sort out and display the significant data.

3. A large number of phone lines would have to be rented if the system were expanded. Not all of CTA's bus line timepoints were near rapid transit phone lines like pilot projects were, therefore lines would have to be rented from each of the timepoints to the CTA headquarters.

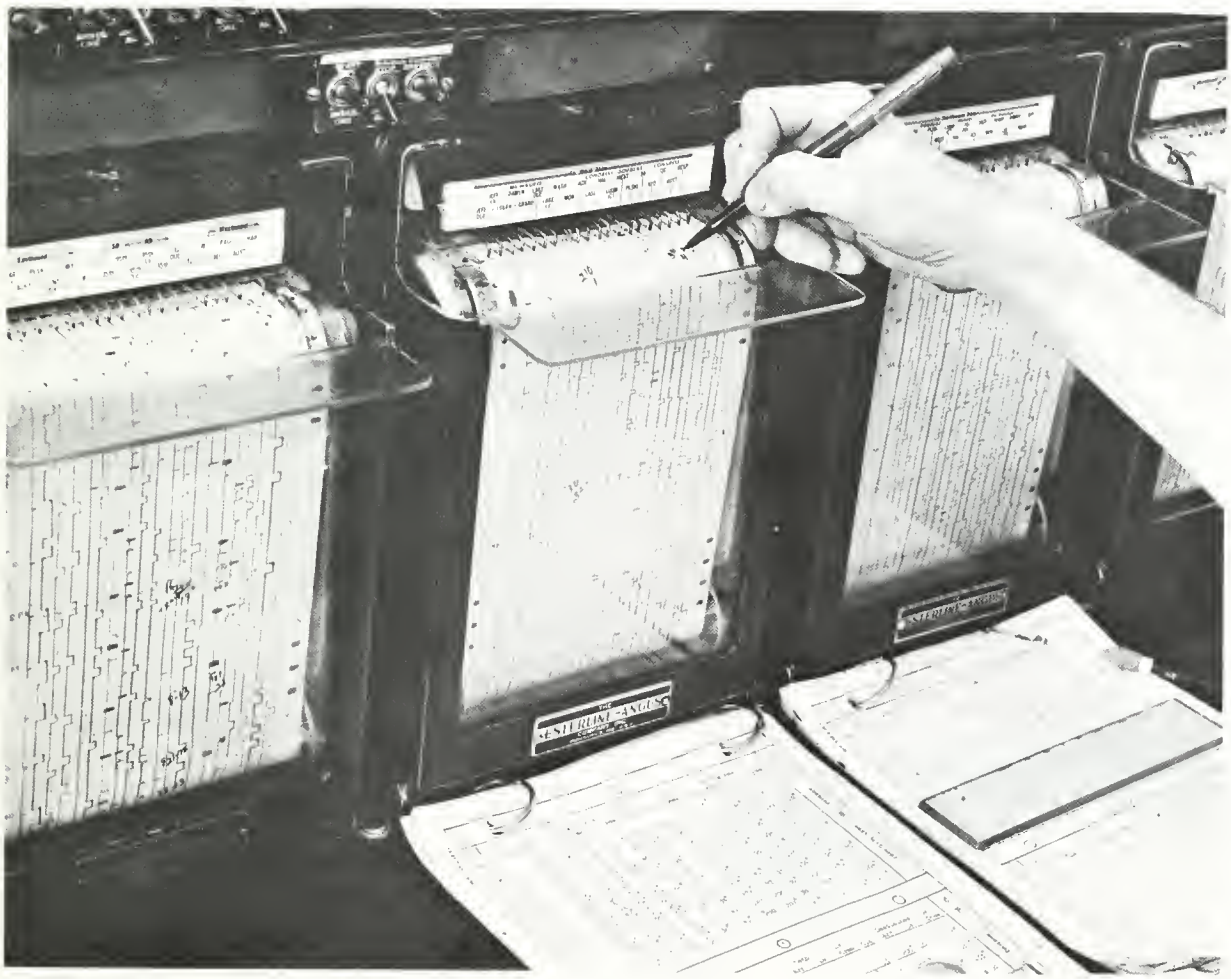
Other systems

CTA was not the only mass transit operation which recognized the need for a centralized headway recording. Systems had been tried in Philadelphia, Pittsburgh and St. Louis by 1955. The American Transit Association had established a committee to investigate the possible applications of AVM equipment.

European transit operators were also working on headway recorder development before 1960. Utilizing the unique double deck nature of its equipment, London Transport managed to solve the vehicle identification problem before bus identification equipment was developed in the United States.

In 1958 London installed an optical scanning bus identification system. A reflectorized panel was installed at the second deck level of each bus. The panel had a series of alternating light and dark strips on it which carried an identification code. The system worked on the same principal with which railway cars are identified in this country today.

Though the system was effective (in fact it is still in limited use today) optical scanning identification would not



Rapid transit system pen recorders

Illustration 8

be practical for American transit operations. Because wayside scanning devices were confused by passing traffic, London had to locate the identification panels on the second deck of their buses above the traffic level. Single deck American buses are not tall enough to avoid traffic interference.

Unfortunately, all the pioneering systems were handicapped by similar difficulties; poor display, high cost, and, with the exception of London, a method to identify moving vehicles. Transit officials agreed that though the development of AVM was important to the future of the industry, pre 1960 technology just did not seem to provide a means to match equipment with concept.

CTA accumulates AVM experience

After the bus experiment was completed in 1958, CTA continued to accumulate centralized supervision experience with equipment used on its rapid transit system. The benefits reaped from the rapid transit system kept hopes alive that a bus monitoring system would ultimately be perfected.

In 1960 a system originally developed for railroad freight car identification, adapted to transit by its manufacturer and CTA, came very close to meeting the needs for adequate bus monitoring. The system provided for automatic vehicle identification (Illus. 10).

Buses were equipped with a pocket sized radio transmitter. When this unit passed a wayside transmitting unit, it absorbed enough power to rebroadcast an encoded run number. The bus transmitter's weak signal was picked up by a wayside receiver. The information was then relayed to CTA headquarters where the signal was automatically decoded.

This system might have been adapted to a computer but cost considerations limited research on the project.

Miniature transmitter used on motor buses in CTA's first use of radio in AVM experiments

Illustration 9

Pocket-sized radio bus identification unit

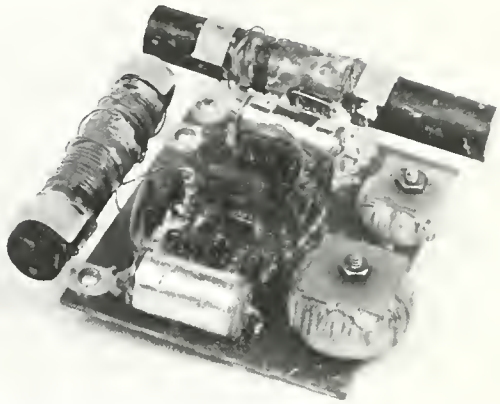


Illustration 10

The computer

The missing link in the development of automatic vehicle monitoring was the computer. Though such equipment did exist during the 1950s, it was quite primitive and very expensive by today's standards. But it was the computer that would eventually provide a means to automatically sort out incoming information and display it in an easily analyzed form.

Computer technology expanded rapidly during the 1960s, but unfortunately another critical element needed to develop the AVM concept was in short supply, money! Most of the nation's transit systems were confronted with serious financial problems. Few had the funds needed for large scale research and development projects. Though CTA was in better financial condition at the time than most other large city transit operations, it too was feeling the pinch of rising costs.

DEVELOPMENT OF THE MONITOR PROJECT

Though there were obvious benefits to be derived from the development of an effective AVM system, CTA's financial condition limited the amount of money which could wisely be spent on an experiment.

A factor which tipped the scales in favor of advancing the development of a vehicle location system was the rise in crime throughout the nation; CTA was not spared from the problem. Cost factors had to be considered secondary when the safety of passengers and employees were at stake.

The solution to the crime problem was seen in the development of a clandestine radio alarm system for buses. Such a system would have to be capable of transmitting location information, the same information needed by an AVM system to function.

Another important factor in the decision to go ahead with the development of an AVM system was the creation of a source of funding for the project. The passage of Urban Mass Transportation Act provided the means to fund an AVM demonstration project.

Therefore, in 1967 CTA committed itself to the development of an AVM system which would include a silent alarm feature.

Object of vehicle monitoring

It was intended that this project would demonstrate the following aspects of vehicle monitoring applied to the transit industry:

1. The practicability of automatically checking schedule adherence of a bus system from a central control center and using the results of these checks to improve service. If this proved practical, a plan to more efficiently utilize personnel could be implemented and a further improved service would result from better supervision. This would also allow reduced equipment requirements for decreased operating costs.

2. The effectiveness of a clandestine alarm system to combat crime aboard transit vehicles, one which gave the identification and location of a vehicle in trouble. If this system proved effective, presentation of this information would increase public safety and improve transit's public image.

3. The possibility of an automated system of this nature to allow more mobile two-way radio units to be assigned to a radio channel. This would result in better utilization of available frequency allocations and conservation of the radio spectrum.

As a part of the project it was necessary to develop a specification for the system. The guidelines used in this development, along with a detailed description of other available types of systems, can be found in the next section

and Chapter II. In the future, other transit systems could apply these guidelines to their individual operations to develop specifications for purchasing monitoring equipment.

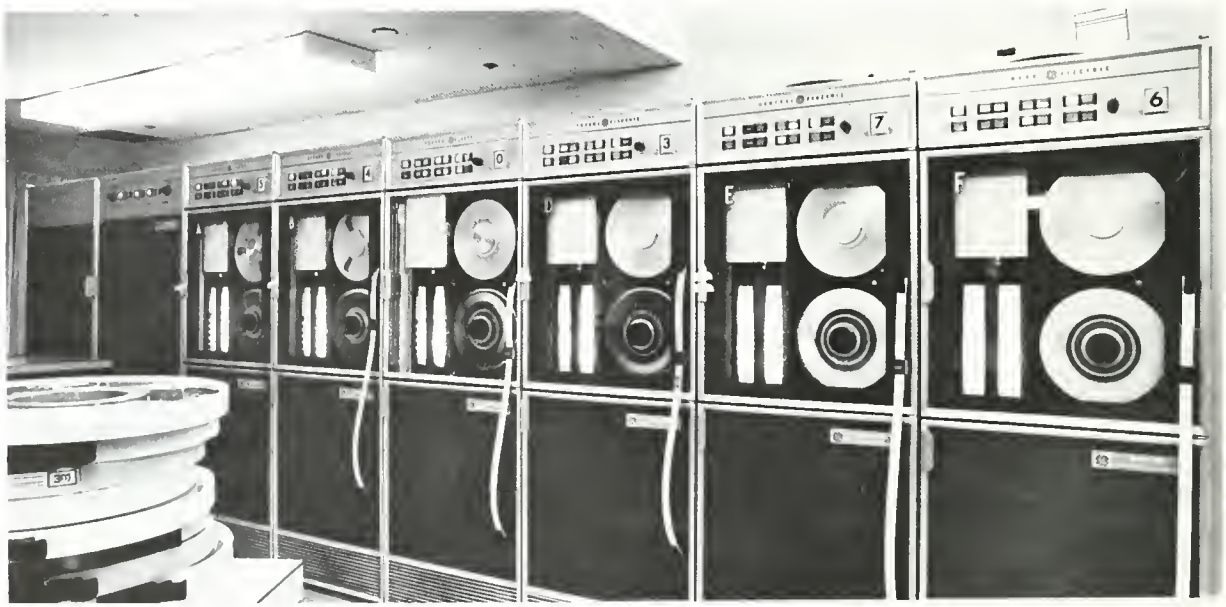
In addition to the specifications, other items of general interest which were developed, include the training materials for various job classifications involved with the system, bus drivers, bus repairmen and dispatchers; these are shown in Chapter III. Also a series of programs were written to assist in the maintenance of the system; these are described in Chapter II.

Performance requirements

Soon after application for the demonstration grant was submitted, specifications were planned. Since a variety of hardware configurations had been proposed, it was decided that a "System Approach" would be the most advantageous. With this in mind, preliminary ideas were set forth into a rough draft. This draft was then submitted to prospective bidders and a consultant for comment. After replies were received and the comments were discussed, evaluated and inserted (or discarded); the final detail specification for a bus monitoring, identification, location, alarm and communication system were prepared.

The accuracy of the system was considered to be a critical detail. Since schedule adherence was to be of fundamental importance in the operation of the system, it was determined that if a bus was located by the system at a point within 15 seconds of its actual arrival, a workable tolerance could be established. Then, by using an average operating speed of 15 mph (22 feet per second) and the 15 second tolerance, a distance accuracy of approximately 300 feet was calculated. Therefore, if a bus was within 300 feet of a timepoint (schedule check point) and was moving at schedule (average operating) speed, its schedule adherence could be determined within $\pm$ (plus or minus) 15 seconds.

The next item of importance was the inclusion of two-way voice communication. This was done since immediate vocal instruction and/or interrogation was deemed an important phase of the project. It seemed there were enough requirements to necessitate interconnections between the voice equipment and location equipment of the system. As a result it was resolved that one prime contractor should have the responsibility of maintaining the whole system.



CTA's business computer

Illustration 11

Many of the systems proposed required the use of a dedicated, special-purpose computer. While originally it was thought CTA's existing G. E. 415 computer could be used for the project, its use would not have presented a competitive bidding situation (Illus. 11). Additional thought was given to daytime operation; if a computer was dedicated to the project, full daytime coverage on some routes could be attempted if it did not hinder bus assignments. Also, some of the evaluation programs might be run on this dedicated computer rather than adding to the load of the existing computer. In addition, the question of system responsibility again arose and prompted the inclusion of a computer in the requirements.

Because this was to be a total system and undivided responsibility was desired, other provisions could be added to insure that a working system would result. It was intended that the prime contractor would have the responsibility of meeting the delivery requirements. A schedule for delivery was set up to allow time for installation and two years of operation; therefore, delivery was to be completed by January of 1970, and, if possible, operation would be begun by June of 1969.

Since there would undoubtedly be many pieces of equipment unfamiliar to CTA employees, training in operation and use of the equipment and the system was added to the specifications. This was to include computer programming, since occasion might arise during the project to modify the operation of the system or the type of data to be derived. Provision was also included for instruction in maintenance of the system. A question arose that the vast amount of equipment involved might overload CTA's maintenance forces, requiring additional personnel. In order to present an alternative to this and to give guidelines for a decision, the vendors were instructed to quote the cost to furnish maintenance for the entire system for two years.

With these items, and many others stating requirements of system and equipment operation, purpose and quality, it was believed the intent of the project would be fulfilled.

Additional features

As the monitor system would have to be able to automatically transmit digital data for its location function, it was thought that the system's data broadcasting capability should be utilized to transmit other types of useful information from the buses. Therefore, it was stipulated that it be possible in the future to expand the system so it could monitor and broadcast such data as passenger counts, fare box readings, mileage and engine status.

Experience with our rapid transit command system indicated that the ability to send simple general instruction codes (start, wait, slow down) was a useful supervisory tool. It seemed that such codes could be transmitted to operators via the digital data channel. So to complete requirements for the system it was determined that the equipment should be capable of two-way digital data transmission.

Area

The area to be monitored by the AVM system had to be determined. It was possible to get (1) city-wide coverage for a small percentage of buses, (2) limited area coverage for a slightly greater percentage of buses, or (3) full coverage for some routes. Full coverage over a selected area was discarded because of the difficulty involved in getting equipped buses assigned to the monitored routes each day, and the resulting decrease in the flexibility of the whole transit system necessitated by specific bus route assignments. The second possibility was discarded due to the geography of CTA's system. Many of the routes cover wide areas making

the separation into small sections extremely difficult. It became apparent that the first approach could be adapted to CTA's "Owl Service," that is, the service between approximately 12:00 midnight and 5:00 A.M. Therefore, the first possibility was chosen.

Coverage over the entire city area provided the best opportunity to test the full capabilities of the system. By equipping virtually every "Owl Service" motor bus with monitor units immediate security benefits could be derived from the system's silent alarm feature.

Sixty motor bus owl routes were chosen for the testing (Illus. 12). Trolley buses were not included in the tests because of their planned phase out. In order to provide monitored buses for all the routes selected and still allow operating stations adequate flexibility in bus assignments it was determined that 500 buses would have to be equipped with the system.

Monitor routes

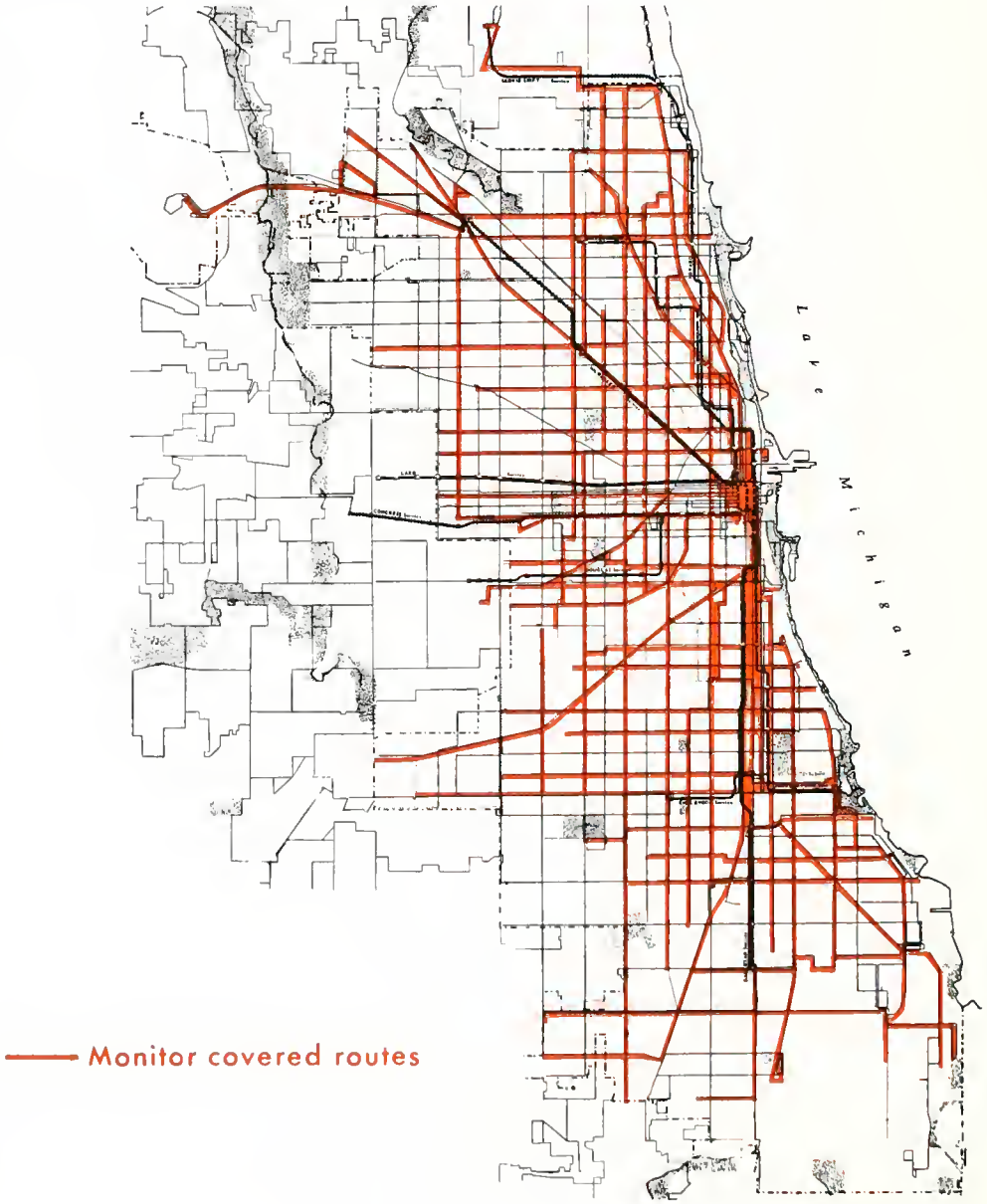


Illustration 12

Contract award

CTA's application for a demonstration grant was approved in March of 1968. Bids for the project were opened on July 16, 1968.

With the low bid, Motorola Communications and Electronics Corporation received the contract award. Bids were also received from Hazeltine and Raytheon Corporations.

Basically the system selected utilized low powered radio transmitters (signposts) located at timepoints to provide AVM unit equipped buses with location references. The on-board bus equipment relays location information to a central computer.

Detailed descriptions of the system and its operation are found in the following chapters.

METHOD OF TEST

Two aspects of Monitor-CTA were to be tested during the demonstration project: (1) The effect of the system on CTA operations, primarily schedule adherence, and (2) the functioning of the Monitor hardware.

Schedule adherence

Monitor-CTA's most important task was to provide a means to apply schedule adherence control to CTA bus routes. A testing program was therefore developed to measure the possible benefits derived from the application of an AVM real time control system.

Nine bus routes were chosen for the testing. The lines were selected to represent typical CTA routes. The limited number made it possible to equip them all with a 24 hour a day fully monitored fleet.

Other similar routes, which were not to be Monitor equipped, were also chosen for the test. The non-monitored routes were to serve as a control group. The control was needed because it was possible that the before-and-after Monitor installation schedule adherence tests might show a change that represented system wide trend rather than the effect of AVM. A method to isolate the Monitor influence was provided by checking control group performance at the same moments the test routes were surveyed.

The standard deviation from schedule before Monitor was installed was then to be compared with the standard deviation on the same route after Monitor was operational. The results would then be compared with control routes to determine if a similar change had taken place. If the Monitored route improved significantly over their pre-monitored period and the control group showed no similar change, it could be safely assumed the change was due to AVM.

The equipment

Monitor could not begin to improve schedule adherence if the system's hardware did not provide reliable data. Therefore, various phases of the system's technical operations were to be subject to testing.

-Signpost range--Since the basis for all location and time measurements of the bus's performance are based on the Monitor-equipped vehicle's ability to sense its proximity to a signpost, the broadcast range of the signpost transmitter is critical. Tests were to be conducted with a Monitor-equipped bus which indicated when it was receiving the signpost signal. The bus was driven past a signpost and measurements were to be taken as to where the bus unit started to receive the signal and where it left the transmitter's range.

The experiment was to be conducted under various weather and traffic conditions.

-Communications reliability--As a high speed radio data system, communications interruptions could pose problems. Therefore, the system's computer was to be programmed to automatically print out any incidents of bus monitor units failing to respond to its radio interrogations. A computer test would provide much more complete surveillance of the Monitor's communication reliability than possible by manual spot checking of radio performance.

-Time accuracy--It was known there were some possibilities for small time errors in the system. Testing the possible extent of the errors was simply a matter of comparing the Monitor reported times with the in the field observations of traffic checkers.

-Location accuracy--The success of the system's emergency alarm depended on the Monitor's ability to locate a bus accurately. Tests were to be conducted by supervisory personnel setting off the alarm in various locations and then comparing their on-the-scene observations with the location calculated by the computer.

-Equipment reliability--As with any complex system accurate records of equipment failures were to be kept and reviewed periodically to spot reliability problems.

CHAPTER II
ENGINEERING

This chapter offers the most detailed explanation of exactly how Monitor works. It was written to provide purely technical information about the function and design of the system's various components. The accent is on system engineering, not necessarily the operational implications of that engineering.

The first portion of the chapter offers brief descriptions of other types of AVM systems considered for application by CTA. A capsule description of the system selected, "Monitor," follows.

The rest of the chapter is devoted to more detailed material. A functional description written with the chronological order of events and the radio signal paths in the system as the basis of organization is included.

The major components of Monitor are then described along with an evaluation of their performance. The various computer programs utilized by the system are described individually in the last section of the chapter.

SYSTEMS CONSIDERED FOR APPLICATION

General discussion of vehicle location

The general problem of vehicle location is one of determining and communicating positions in a two-dimensional environment, i.e., a plane, since the earth's curvature can be neglected. Since it is desired to accomplish this automatically, no human inputs or communications are to be required. Hence, the location scheme must have a reference system and some means of measuring or otherwise determining coordinates with respect to the reference. In addition to the capability of determining positions, the system must be able to communicate this information to a central point (or points depending on operational requirements) and to identify the individual vehicle involved.

Coordinate systems for specifying location

There are a number of means of specifying positions in a plane. All are dependent on knowledge of appropriate angles or distances which must be measured via sensors in the equipment. Six possible reference systems are listed below with short discussions. Any location system other than the first two will have to have the facility for changing the system coordinates to either Cartesian or Polar Coordinates at the final output to a human operator (the dispatcher, for example).

The possible reference systems are:

-Cartesian Coordinates (x, y or rectangular coordinates) - location is specified by two distances along a mutually perpendicular axis. One common reference point is required. This is the most "natural" system for a human operator and is compatible with cities having rectangularly laid out street systems (Illus. 1).

-Polar Coordinates - one angle and one distance are specified from a single reference. This is a "natural" system that man commonly uses for navigation (with compass). It is also the reference system of the usual radar transponder system (Illus. 2).

-Triangulation - three reference points are required with angles to or from the target being measured. Two angles may be sufficient if the vehicle travel is restricted so that it does not approach the line connecting two reference points. This system is used in radio direction finding (RDF) systems.

-Measurement of Three Distances - the distance to three reference points are measured. As with triangulation, only two are required if vehicle travel is restricted. This locates the vehicle at the intersection of two (or three) circles. The locus of the vehicle's travel, if one distance is held constant, will be circular. This type of location information is obtained by taking two (or three) measurements with an aircraft's DME equipment.

-Measurement of Two Differential Distances - two measurements are made of the difference in path length to three reference points. Location of the vehicle occurs at the intersection of two hyperbolas. The locus of travel for one constant path difference is hyperbolic. Loran type systems employ this reference system.

-Measurement of Two Differential Angles - two measurements of the difference in angles to three reference points are made.

Location determining techniques

There are three basic techniques available to determine position in any reference system. One technique is the establishment of a "coded" environment. The other possibilities are direct measurement of the appropriate angles or distances using radar-like techniques and finally the use of indirect or derivative measurement. These techniques are discussed individually below:

-A coded environment technique is the means that people use most commonly to determine location. This is nothing more than noting prominent landmarks, street numbers, and signs, or any other cues which are a fixed part of our environment. We then relate the cue to our memory or reference system to fix our position. The significant point is that our environment is permanently marked or coded with the required cues. Society has gone to considerable expense to establish a street number system and directional signs in cities and on roads. Without these, one would be hopelessly lost in unfamiliar areas.

Unfortunately, electronic devices cannot "read" the visual cues established for man. It is possible, however, to establish an artificial "environment" which would contain radio cues or perhaps some other type of cues which might be read by a suitable device.

-Direct measurements can be obtained by transmitting suitable signals between a vehicle and one or more reference points. It is then

Cartesian coordinates

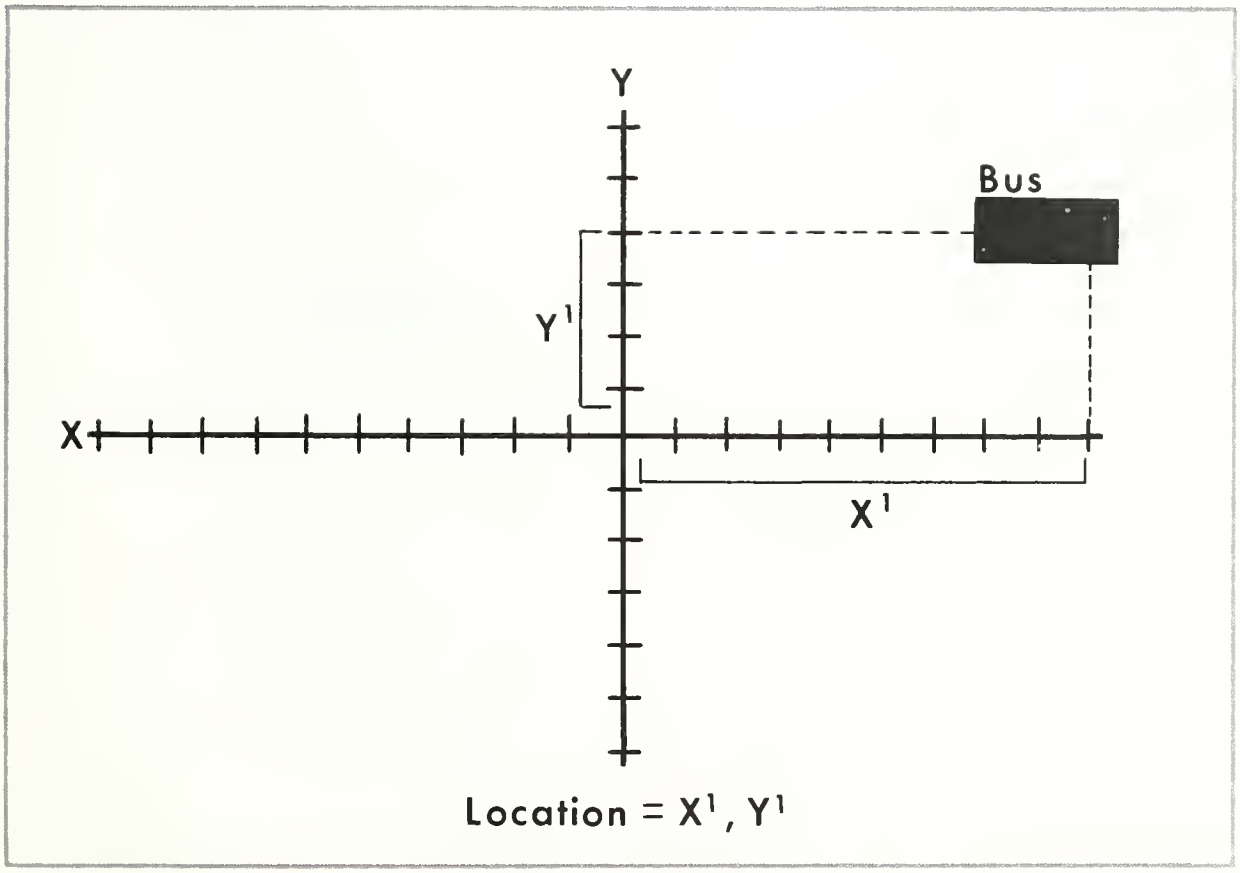


Illustration 1

possible to measure position directly. The measurements consist of a set of angles and/or distances as previously described.

Two types of signals are available. One, electromagnetic radiation, includes a broad spectrum from commonly used radio frequencies through infrared, visual light, and ultraviolet frequencies. The other possibility is sound waves, both sonic and ultrasonic.

Directional antennas are used to measure angles. Distances are obtained by measuring the time required for a wave to propagate over the desired paths. This is readily translated into a distance measurement since the velocity of propagation is relatively constant.

Sound has an advantage over radio for this application in that its velocity is much lower. Hence, the required timing accuracy is greatly reduced. However, sound is attenuated much more rapidly. For the latter reason, radio is the principal signal used in direct measurement systems except possibly over short distances. Of course, the radio frequency spectrum is large and different frequencies have considerably different propagation characteristics. The choice of radio frequencies is further complicated by FCC licensing which becomes an important consideration.

-Derivative measurement is used in missiles and nuclear submarines to determine location by a system known as inertial guidance. Instead of directly measuring position, this type of system measures changes in position (velocity or acceleration) and integrates these to derive location information. This is analogous to using a compass in navigation. One keeps track of the distance traveled in each direction taken. Knowing the starting point, it is a simple matter to calculate position at any point along the route.

The principal technical problem in

Polar coordinates

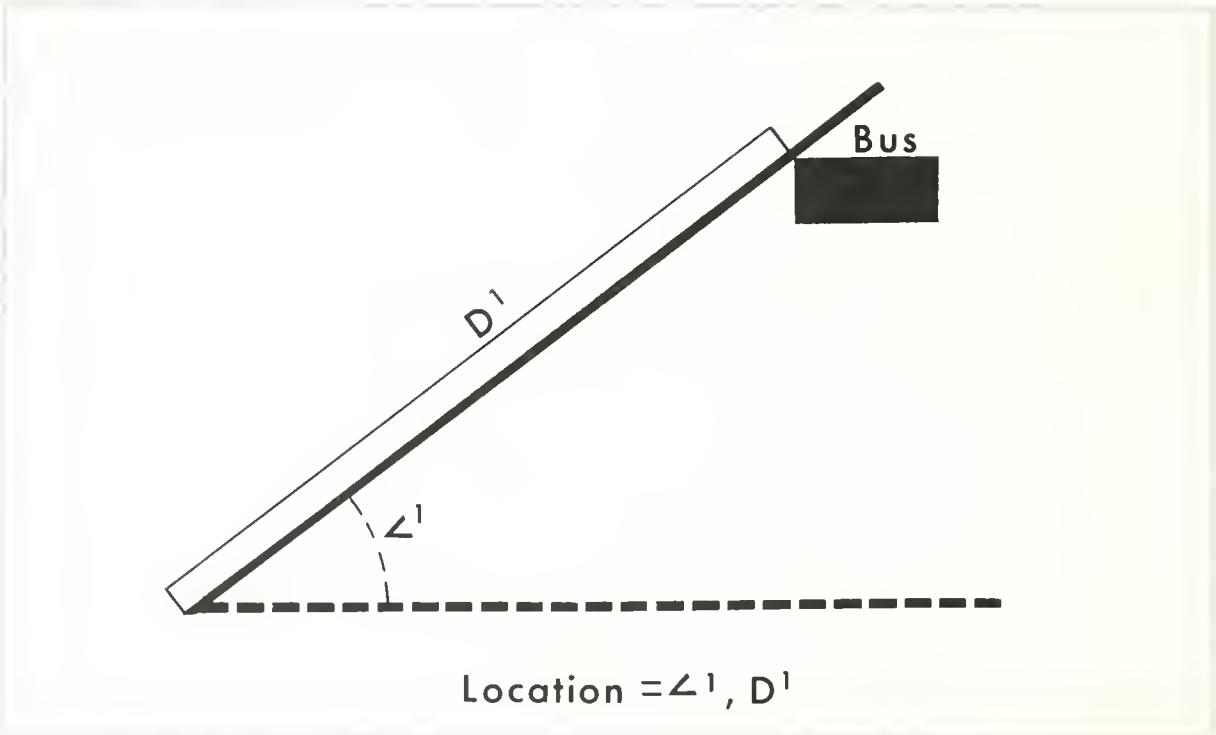


Illustration 2

this type of system is the accumulation of errors in the integration process and the attendant need to correct these errors in each vehicle.

Possible system approaches

Several system types are described below to show the wide variety of systems which could meet the requirements for a transit location system. In particular, for the sake of brevity, only two direct measurement approaches have been described.

-The Radar Transponder System utilizes a directional antenna array which would be located at one or more fixed reference points. Angular information would be obtained by rotating the antenna pattern. To obtain sufficient precision, a nulling technique employing two slightly offset antennas or electronically switched elements would be required. Distance information would be obtained from a transponder in the target vehicle by measuring the time for an interrogation from the fixed site to be answered by the vehicle. Through the use of phase correlation measurements, the transponder function might be provided by the normal two-way FM radio in the vehicle plus a few additional circuits.

Advantages:

a. A minimum of fixed reference sites are required, and possibly only one of adequate coverage can be obtained.
b. The directional antenna can also provide better voice coverage if a compatible FM transponder is used.
c. A "natural" polar coordinate reference system results which will not require translation to another system.

Problem Areas:

a. Both bearing (angular) and distance measurements can be affected by multipath propagation. The entire magnitude of this problem is difficult to ascertain.

b. A compatible FM transponder may not provide sufficient accuracy. In this case a unique transmitter and receiver would be required in the vehicle and a special wideband frequency assignment would be required.

Example of a 'multi-path'

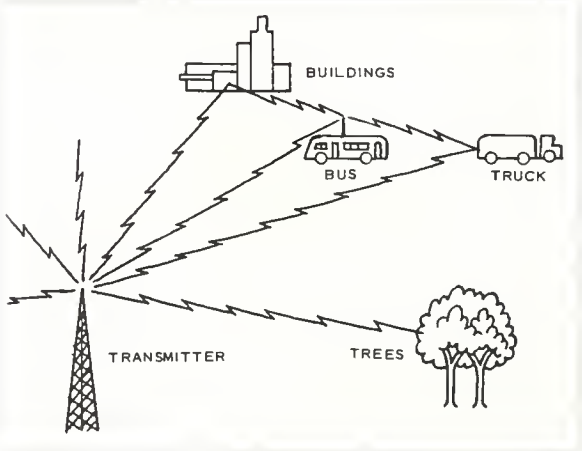


Illustration 3

-A Hyperbolic System requires that three reference points with receivers be established to make comparative measurements of the time delay resulting in a signal transmitted by the target vehicle. If a conventional narrowband FM transmitter is used for the vehicle signal no new transmitters are required.

Advantages:

a. Potentially low cost vehicle-mounted unit.
b. No new base station transmitters.

Problem Areas:

a. Hyperbolic reference would require computer translation to a system useful to human operator.
b. Narrowband FM transmitters may not provide sufficient accuracy.
c. Multipath propagation may introduce large errors (Illus. 3).

-Electronic Signposts are small inexpensive transmitters that would be located in a grid fashion throughout the area of interest. They would radiate a short range signal giving their location code. Vehicles would receive this code and store the last one received. This would be relayed on interrogation to the central station.

Advantages:
a. Low cost mobile unit
b. Freedom from effects of multipath propagation.
c. Direct readout of any desired reference system coordinates.

Disadvantages:
a. Large number of signposts needed to obtain desired resolution.
b. Location of bus cannot be exactly determined between signposts.

-The Derivative (Compass Speedometer) system requires each vehicle to keep track of its location and transmit this information to a central location upon interrogation. The vehicle would keep track of position by integrating velocity from the speedometer and heading from a special compass. This system could be combined with an electronic signpost system so that a very crude integration process would suffice and the system would automatically remove errors.

Advantages:
a. Freedom from effects of multipath propagation.
b. Assuming the usual FM radio is used for interrogation, no new radio equipment is required.

Problem Areas:
a. Unknown accuracy of compass in a vehicle over long term.
b. Unknown cost for various accuracy requirements.

-The Use of Existing Radio Signals is possible because the environment is filled with various types of radio signals. It is possible that measurements of existing signals could provide location information without additional transmitters. For example, the horizontal oscillator synchronization component of a T V broadcast signal could provide a reference signal with extremely good coverage in most cities. Broadcast band AM and FM stations are other possibilities. By correlating signals received at a mobile and a fixed reference receivers, distance would be determined. The present F M radio would be used to relay the measurements.

Advantages:
a. No new transmitters
b. Excellent coverage essentially "free."

Problem Areas:
a. Selection of signals would be specialized to each locality.
b. Problems in obtaining 24-hour operation.
c. Unknown accuracy.

MONITOR CTA THE SYSTEM SELECTED

The operational characteristics of a metropolitan bus transit system have several unique properties which were taken into account in selecting the final approach to be implemented in the Monitor-CTA system.

-Buses move over a fixed, defined route structure. Random movement of vehicles is virtually non-existent, hence the ability to pinpoint the exact location of a vehicle at points other than on its assigned route was thought not essential.
-The principal common dimension in operating the bus fleet is time. Schedules for every bus operating on

every route are determined, running times established, with intermediate time check points designated to regulate movement over the entire route. These time check points represent the "coded environment" mentioned previously. For a system intended to optimize schedule adherence, the exact location of a bus is not as important as its location at a point in time relative to these time check points.

-The relative constant speed of buses in the system allows acceptable interpolation between the time dimension and speed dimension to derive the physical location of a vehicle on a given route. This could be utilized in aspects of the system other than schedule adherence, e.g., emergency situations. Where required, speed profiles of the route can be derived and used to accommodate variations between routes and/or variations in running times on the schedule for seasonal changes (winter / summer) or time of day (rush hour vs. nite-owl service).

Location aspect

Based upon the considerations of the preceding paragraphs, a combination of the Electronic Signpost and Derivative methods was chosen as the best means to implement a location system.

The essential elements of the vehicle location portion of this system are listed below:

-A Control Center, including a computer and its peripheral equipment, dispatcher consoles, and also encompassing the base station transmitting and receiving equipment.

-Signpost radio transmitters placed throughout the city of Chicago.

-Two-way radio and data equipment located on the bus utilizing an electronic timer to derive intermediate location (Illus. 4).

Block diagram of signpost and bus location components

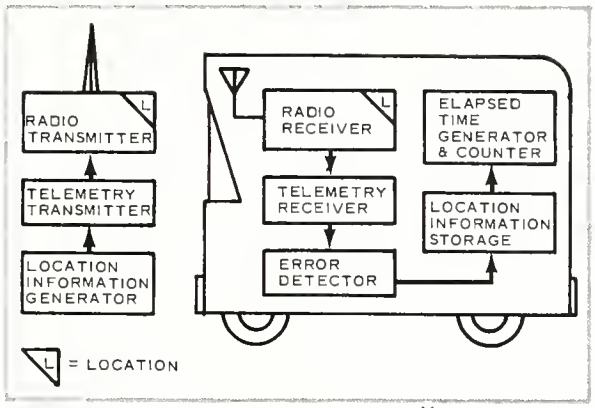


Illustration 4

The computer at the Control Center initiates the information gathering cycle to determine the location of a given bus. (A schedule is stored in the computer for each of the runs in the system.) The number of the given run is provided by the computer to the data channel base transmitter. This transmitter sends the run information in the form of tone coded signals over the "air", allowing each bus in the system to receive them and determine if it is the one being called. In the bus, the run number signals are received through the data channel receiver. Since each run has a different number, only one bus will be capable of answering at any time. Upon entering the bus at the beginning of each run, the bus driver sets the bus address corresponding to the run number onto thumbwheel switches (Illus. 5).

In the given bus, when the received identification number signals agree with the setting on the thumbwheel switches and the prewired garage number, the interrogate portion of the cycle is complete, and the reply portion now begins.

The reply information consists of the number of a fixed "signpost" placed along the bus route, and an elapsed time indication. (There are a number of such signposts placed throughout the City.) As the bus passes a signpost,

the signpost location number, in the form of tone coded signals, is sent to the bus by the location radio transmitter. In the bus, the location radio receiver accepts these signals and stores them in the location information circuitry.

Upon interrogation, the location number and time indication are transmitted back to the Control Center by tone coded radio signals through the bus data channel transmitter. At the Control Center the data channel receiver at the base station accepts the information and presents it to the computer through appropriate interface circuitry. The computer then compares the received information with the programmed information stored in its memory. If they agree, no further action is required. If they disagree, the computer determines if the information shows the bus to be early or late, and by how much. It automatically provides this information to the dispatcher by a Visual Display on a cathode ray tube. The dispatcher determines whether any corrective measures are required.

Setting thumbwheel switches

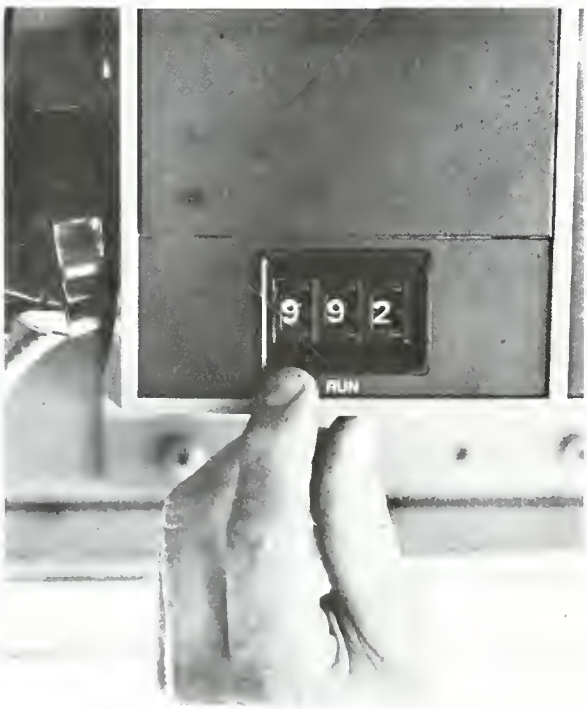


Illustration 5

Alarm aspect

A second important feature of the system is its alarm capability.

A non-voice method of alerting the dispatcher to serious problems of an emergency nature is provided in this system. When trouble occurs, the driver unobtrusively activates a concealed switch which immediately and automatically transmits an alarm signal over the voice channel. There will be no indication to the criminal that a transmission is under way. Tone coded information is generated within the bus electronics and sent back to the Control Center on the voice channel. The information consists of bus address, its location and elapsed time indication, and the bus "number."

At the Control Center, the information is received by the voice channel receiver and is processed by an identification and alarm decoder. The output of this decoder controls a visual display and the computer input.

Voice operation

In addition to location and alarm capability, the system is capable of normal two-way voice communication. The dispatcher, at any time, can call and communicate with one or more buses on a selective basis. The driver can also originate a call by simply picking up his handset, depressing the push-to-talk button, and talking. Voice communication is available on an immediate basis, and without the necessity of the driver leaving the bus.

Extended capability

Capability to allow for the transmission of digitalized monitor data for other bus functions (such as mileage, number of passengers, engine status and others) are provided in the basic system design. The obvious benefit is that these functions can be incorporated readily and at minimal cost at some later date.

EQUIPMENT FUNCTIONAL DESCRIPTION

This detailed system description explains each of the three principal operating modes of the system, using chronological order and the signal path of the information as the basis of explanation.

Bus location hardware

The bus locating mode is a data retrieval system in which information acquired by and stored within the bus, is periodically called for by the Control Center and sent in by the buses over a radio communication link.

The buses receive location information from low-power transmitters placed throughout the City. Each of these stations, known as Signpost Location Transmitters, has a number assigned to it which is different from all other Location Transmitters. Therefore, merely knowing the number of the transmitter is the same as knowing its position in the City.

Each of the Location Transmitters has an associated Location Information Generator which continuously generates, in digital form, the number which has been assigned to the Location Transmitter site. The number that is generated consists of a series of ten digital pulses, which are fed into a Telemetry Transmitter which converts the pulse into tones. The tones are then used to modulate the Location Transmitter in a manner identical to voice modulation, and sent out over the air. The Location Transmitter is a low power device which results in a limited range of transmission. The purpose of using a short range transmitter is to require a bus to be quite close to the signpost to receive information, and thus prevent accidental reception of information from one or more incorrect Location Transmitters. The range of the transmitter is such that a passing bus must be within a radius of approximately 200 feet in order to receive the location site number. The Location Transmitter and the Location Information Generator are shown in Illus. 6.

Signpost interior and block diagram

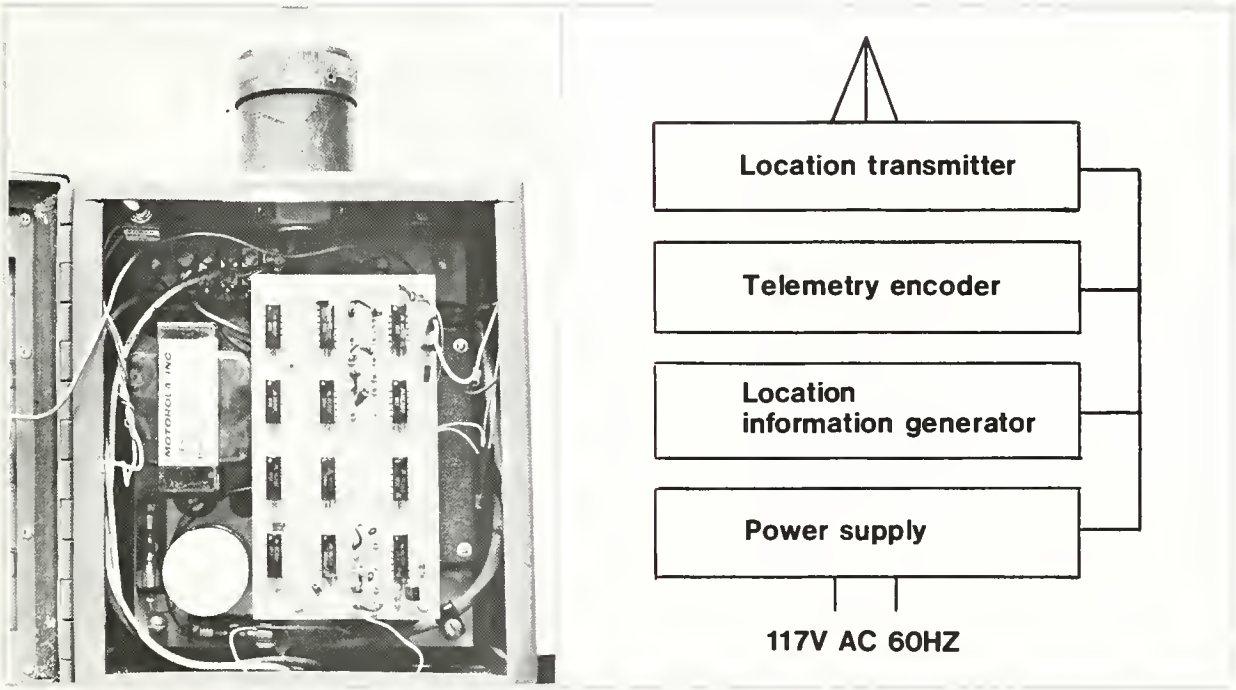


Illustration 6

Bus equipment

The number of the location site is received repeatedly by the bus while it is within the range of the transmitter. Each time it receives a new number, the bus stores the information until it acquires another new number. The Location Receiver and the simplified information storage block are shown in Illus. 7.

The tone modulated radio frequency signal is received by the Location Receiver in the bus. The tone information of the receiver output is fed to the Telemetry Receiver. The process occurring here is exactly opposite to that in the Location Transmitter. In the Telemetry Receiver, the tones are reconverted into a series of digital pulses. The digital pulses are then applied to an Error Detector, which makes certain that the message has been received and repeated correctly.

Bus location equipment

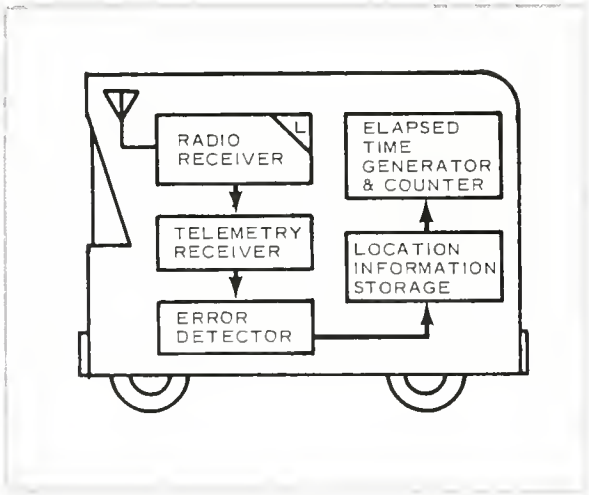


Illustration 7

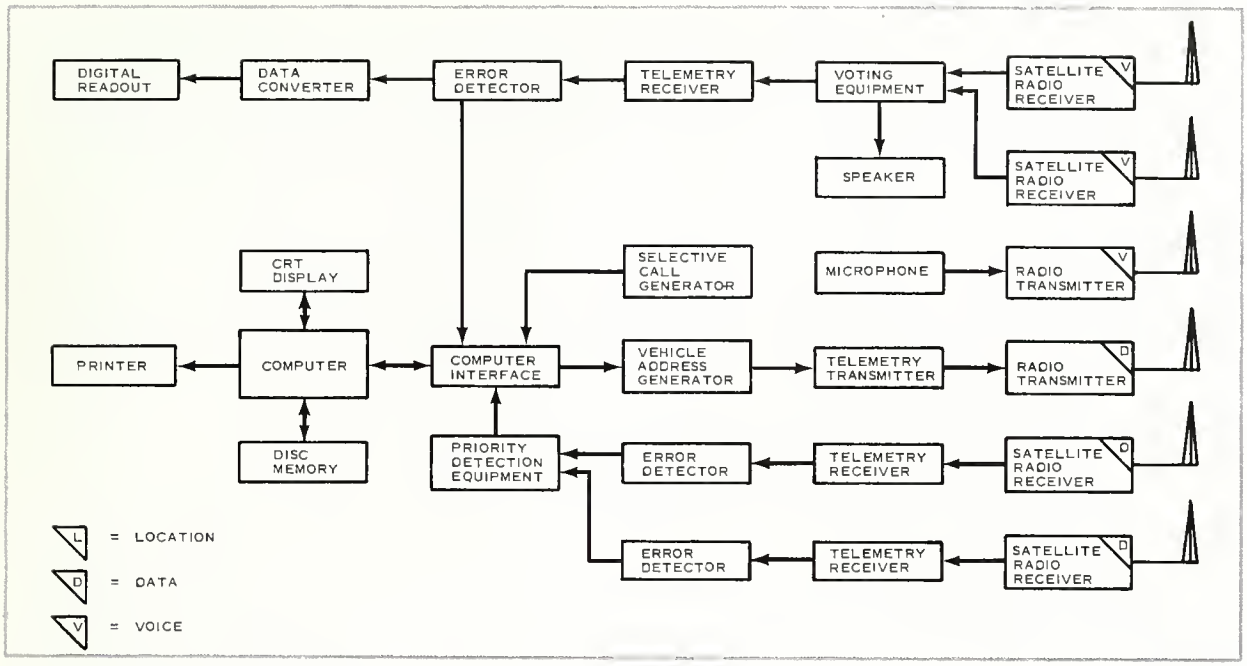
After the location site data (which is in the form of a ten bit digital number) has been checked by the Error Detector and found to be structurally correct, it is fed into the Location Data Storage device, where it is retained until replaced by another correctly received number. This Location Data Storage circuitry retains the number of the last location site that the bus passed until the bus is automatically interrogated by the Control Center.

An Elapsed Time Generator is used in conjunction with the location storage circuitry. This device consists of an accurate 12 second (0.2 minute) timer and digital counting circuitry. After each new location site number is entered into the storage circuitry, or when the same site number is reentered into storage, the Elapsed Time Generator is reset and begins counting the number of 12 second intervals that have occurred since the last entry. The current number of the 12 second intervals is then sent back with the location site number whenever the bus is interrogated by the Control Center. This tells the Control Center within 12 seconds of how long ago the bus passed that reported location site. The effect of the elapsed time generator is to increase the resolution of the system to a situation analogous to asking the bus its location every 12 seconds. The insertion of a 6 second bias into the computer provides a mean from which time deviation to within one tenth of one minute accuracy may be reported. At nominal bus speeds, this represents a distance of less than 135 feet.

The incorporation of a five bit binary storage for elapsed time allows for over six minutes of elapsed time storage.

Control center

When the system is in the location mode, the Control Center performs the functions of interrogating (asking) each of the buses in turn for its location information (including location site number and elapsed time count) accepting the returned data, and processing this data for proper visual readout and recording. The heart of the Control Center is a digital computer. This device has the schedule of the bus system within its storage circuitry. Using this



Block diagram of control center **Illustration 8**

schedule as its basic instructions, the computer provides, at the proper time, the run number of each bus to be interrogated, it then compares the data returning from the bus with the schedule. If any bus is not on schedule or within certain limits of the schedule, this fact is displayed for the personnel at the Control Center.

Refer to Illus. 8 for a functional diagram of the Control Center. The location data retrieval process begins with the computer providing the Vehicle Address Generator with the identification number of the bus to be interrogated. This information is passed through the Computer Interface, a device which provides for the proper language and timing of signals between the computer and other associated equipment. The Vehicle Address Generator accepts the five digit identification number from the Computer and converts it into a series of digital pulses. These pulses are then converted into tones by the Telemetry Transmitter, and are in turn used to modulate the Data Transmitter. The Data Transmitter then sends the information over the air to the buses.

Referring to Illus. 9 each bus receives the signal from the Control Center through the Data Channel Receiver. The tone outputs of the Data Channel Receiver are fed into the Telemetry Receiver, which converts them into digital pulses. The digital pulses are then routed to the Error Detector, which makes certain the message has been received correctly. The five digit identification number is then fed into the Vehicle Address Comparator, which compares the number against the setting of the Thumbwheel Switches (run number) and the prewired garage number in the bus. Each time the driver begins a new run with his bus, he sets the run number into three Thumbwheel Switches accessible to him.

The three digits of the run number, plus two digits representing the garage from which the bus originates, comprise the five digit address which the Address Comparator uses to compare the incoming address. (The two digit garage number is variable from 1 to 15 to accommodate the existing 11 garages plus future expansion.) When these two numbers are the same, the comparator

activates the data transmission process in the vehicle. The Data Channel Transmitter in the bus is now turned on, and the Data Scanner converts the information stored in the location storage circuitry and the Elapsed Time Generator into a series of digital pulses. In a process identical to that occurring in the Control Center, these digital pulses are fed into a Telemetry Transmitter, which converts them into tones for modulating the Data Channel Transmitter. While the data scanning process is occurring, no new location information is allowed to enter the Location Data Storage circuitry, thereby preventing the transmission of a location number which has been only partially received by the bus. Upon completion of the data scanning process, the Telemetry Transmitter is turned off, and the data receiving circuitry again begins comparing successive addresses for the correct code. The location storage circuitry also begins to receive new location site numbers if the bus is within range of a Location Transmitter, or retains the previous number in the event that the bus has not passed a new Location Transmitter before again being interrogated.

The data transmitted by the bus is then routed back to the Control Center. The mobile transmitters have less range than the Control Center transmitters due to the combination of less output power capability and lower antenna height. To overcome this problem, several satellite receivers are located throughout the City, and are connected to the Control Center by leased telephone lines. This allows the reply data from any bus to be received by the Control Center. Priority detection circuitry compares the decoded signal output from the Error Detector associated with each Satellite Receiver and routes the first legitimate data to the computer. See page 45 for a description of the receiver voting system.

The location information is now processed by the Computer to ascertain whether it conforms to the schedule. Secondly, the elapsed time number is subtracted from the time at which the Computer interrogated the bus to determine the exact time when the bus passed the reported location site. From this data, the Computer determines how far ahead or behind the bus is from the schedule. If the bus is off schedule by more than the given toler-

Interrogation mode equipment

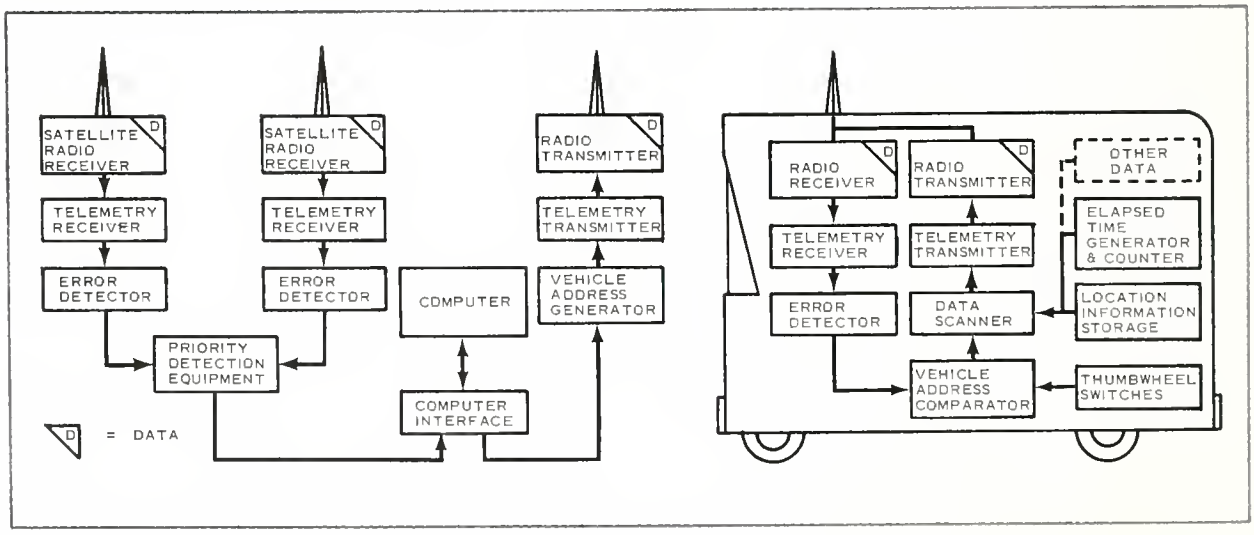
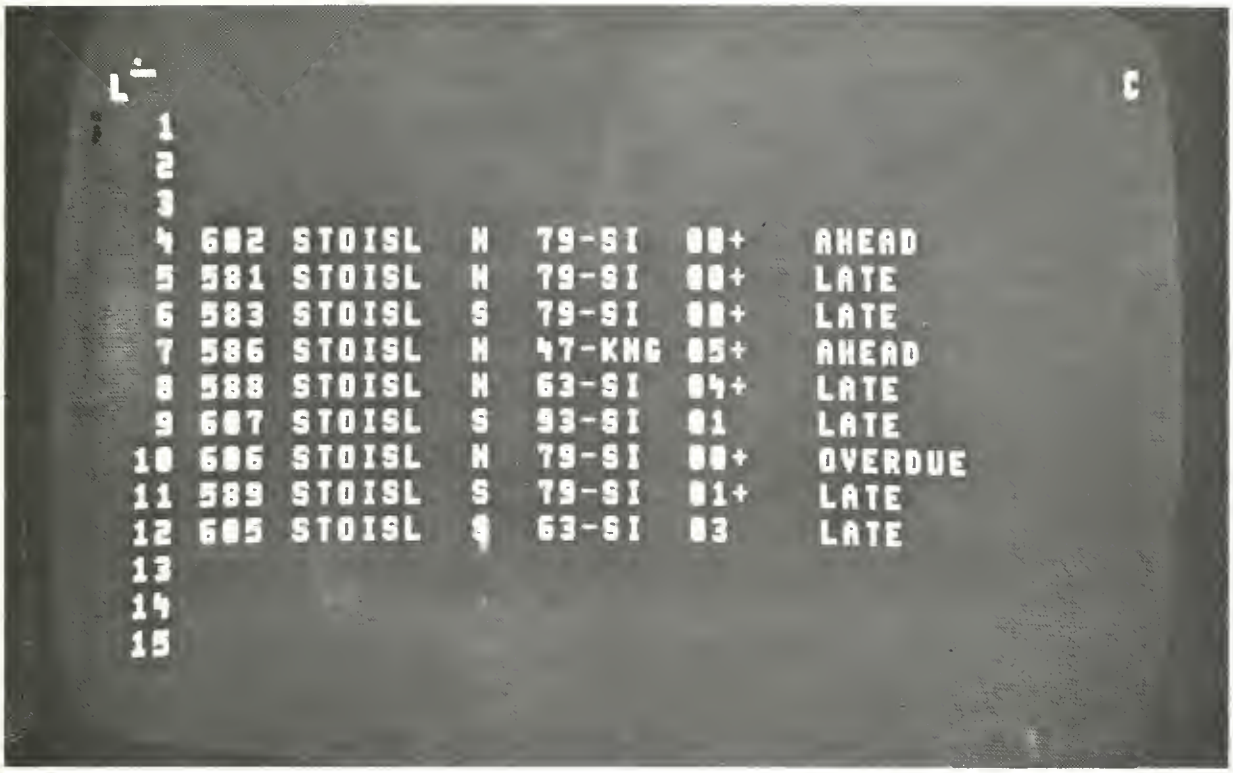


Illustration 9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4 602 STOISL N 79-SI 00+ AHEAD
5 581 STOISL N 79-SI 00+ LATE
6 583 STOISL S 79-SI 00+ LATE
7 586 STOISL N 47-KNG 05+ AHEAD
8 588 STOISL N 63-SI 04+ LATE
9 607 STOISL S 93-SI 01 LATE
10 606 STOISL N 79-SI 00+ OVERDUE
11 589 STOISL S 79-SI 01+ LATE
12 605 STOISL S 63-SI 03 LATE
13
14
15

CRT display

Illustration 10

ance, appropriate information is provided to the dispatcher. (All of the data retrieved is stored but does not usually generate a display.)

Off-schedule data can be recorded magnetically, or on a printer which provides hard copy for record purposes. A common printer serves all dispatchers in the Control Center.

The dispatcher has a control console from which he can voice communicate and observe the scheduling data of the buses under his jurisdiction. Included as part of the console is a CRT (Cathode-Ray-Tube) Display. This device displays all information pertaining to off-schedule buses. A typical CRT display of an off-schedule bus is shown in Illus. 10.

An added feature of the CRT display system is that if any dispatcher's CRT is completely filled, and additional information comes in, then this "overflow" information can be routed to a supervisory console. The supervisor can take extraordinary measures to correct the problem, either by implementing corrective action for the buses or by adjusting the scheduling tolerances in the computer to lessen the scheduling requirement.

The timing of events for the data interrogation and retrieval portion of the bus system is shown in Illus. 11. The several aspects of the location mode are shown on this diagram under the sections "Mobile to Base Data Reply Format" and "Location and Interrogations." It should be noted again that the bus interrogations and the corresponding replies from the buses occurred on separate RF frequencies. This fact is significant because it means that the dispatcher can selectively call a bus for voice communications during the reply of the first bus.

At time T-0 the control center begins to transmit the address of the first bus, and completes it at T-1. In the proper bus, the address is recognized at T-1, which causes its transmitter to be turned on; this is shown on line 3 as "Initiate Reply." After the mobile transmitter has been turned on and comes up to power, the data reply is

transmitted from the bus (T-3 through T-5). While this is occurring, the dispatcher can transmit a selective call address to a desired bus (T-2 through T-4). No interference occurs since the interrogations are transmitted on a different RF frequency than that of a location reply and the selective call reply will be via the voice channel. At time T-6 the second bus is addressed for its location. The total time required from the beginning of the first interrogation to the beginning of the second is 83½ milliseconds. This allows for the complete figure to be repeated up to 720 times each minute.

Alarm hardware

Unlike the location mode of the system, which is initiated by the Control Center, the alarm feature is initiated by the bus driver. The alarm feature is used whenever the driver encounters an emergency situation where he cannot safely communicate by voice. The prime example of such a situation would be during a robbery, where an attempt by the driver to voice communicate with the Control Center would increase his chances of receiving bodily harm. With the alarm feature, all the bus driver has to do is discretely activate a switch; this turns on the radio and automatically transmits the identification of the bus along with the location information stored in the bus. For added safety, the light which normally indicates an active radio transmitter is not illuminated.

The diagram shown in Illus. 12 represents the mobile and control center of the alarm system. The alarm is initiated by the operator depressing the switch. This action causes the Voice Channel Transmitter to be activated, and starts the Data Scanner. The Vehicle Identification Generator uses the setting of the Thumbwheel Switches (run number) to generate part of the vehicle identification number. This number, along with the garage and bus numbers and the location information is transformed into a series of digital pulses by the Data Scanner and fed into the Telemetry Transmitter. The Telemetry Transmitter converts the digital pulses into coded tones, which are then sent by the voice transmitter back to the Control Center. The alarm message from the bus is continuously repeated for a

Message formats

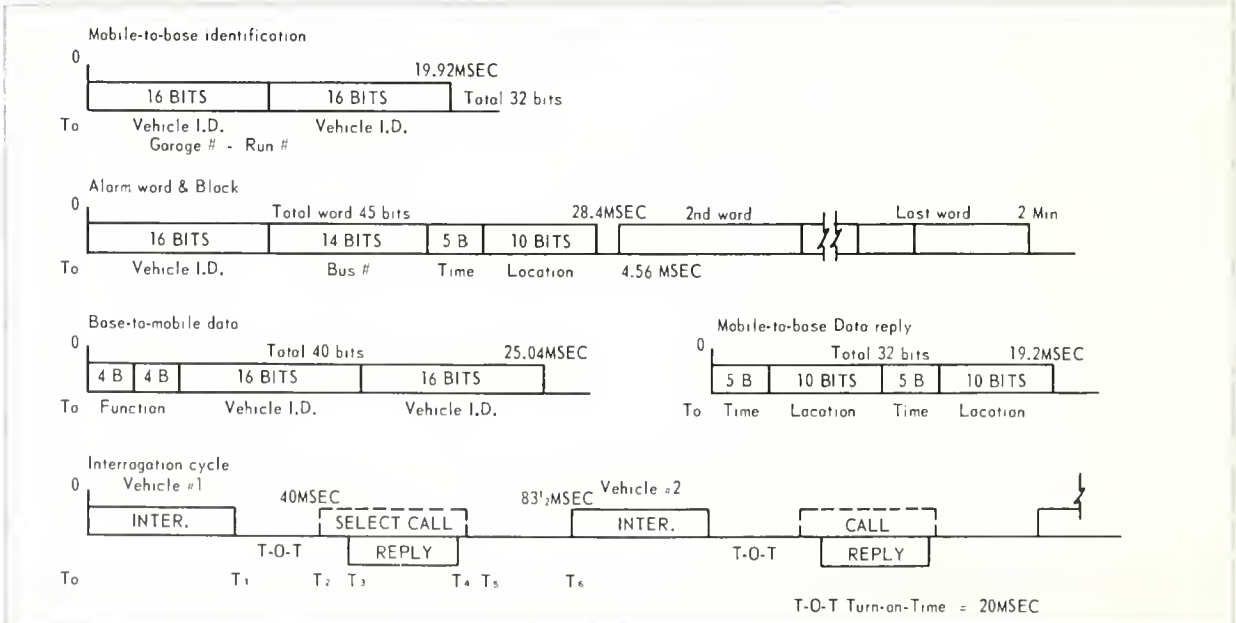
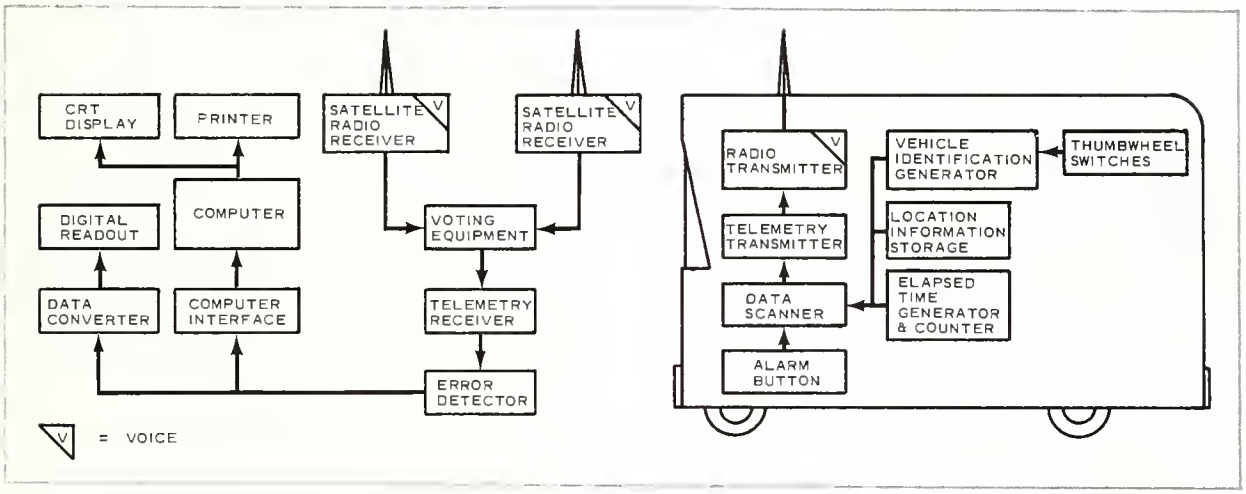


Illustration 11

period of two minutes to insure that it is properly received at the Control Center without interference from voice messages on the channel. At the end of the two minute period, the radio reverts to normal operation.

The voice talkback path is identical in operation to the data reply path with one exception. Instead of having receiver selection circuitry controlled on a priority basis, receiver voting is used to select the proper satellite receiver. The voting system is described in the voice hardware section.

The coded tones from the receiver having the best r-f (radio frequency) signal are routed by the voting circuitry



Block diagram of alarm system **Illustration 12**

to a Telemetry Receiver, where they are converted into digital pulses. The pulses are then checked by the error detection circuitry and passed to the Data Converter. This converter provides the data in the form of a fourteen digit identification location number, which is displayed at the console on a digital readout. The information is also displayed on the CRT and is printed out as a pernament record on the printer associated with the computer system.

When an alarm is received at the Control Center, an audible alarm is activated, thus alerting the dispatcher to monitor the digital readout and CRT display. The dispatcher alerts the police and instructs a supervisory car to proceed to the bus. An important feature of the alarm system is that it is not completely dependent upon the Computer, as all necessary basic information is also contained in the digital readout. Thus, if the computer is out of service, the alarm system will still function.

Voice hardware

The system includes the capability for normal voice communications, as well as for location and alarm functions. Voice communications can be initiated by either the dispatcher or the bus driver. When the dispatcher desires to contact a specific bus, he selects the identification number of that bus on the Selective Call Generator located on the console. The Selective Call Generator provides a code similar to the interrogation address used in the location retrieval system. This selection call signal is then injected into the next vacant space between two vehicle addresses of the interrogation data stream as shown in Illus. 13. It is possible to utilize these vacancies or free spaces between adjacent data interrogation addresses because the selective call does not initiate a reply by the bus on a data channel.

The selective call code is received by the Data Channel Receiver in the bus and processed in a similar manner to a vehicle address interrogation. The Vehicle Address Comparator recognizes

the correct address of the bus, but instead of initiating a data reply, it activates the Selective Call circuitry, alerting the driver to the incoming call. Another feature of the selective calling system is that the dispatcher can, with the controls provided, call groups of buses when required.

The purpose for having the selective call procedure is two-fold. First, it permits the dispatcher to call any particular vehicle without disturbing the others on the channel. Secondly, the selective call function allows a single transmitter/receiver to be used in the bus for both voice and data communications. The bus radio is normally in the data mode receiving bus addresses and transmitting back location information.

When a particular bus is selectively called for a voice message, the bus is removed from the data system for a length of time that the handset is removed from the control unit, but the remainder of the data retrieval system is not disrupted. If voice communications are occurring while a bus is being interrogated, the bus will not receive the data interrogation and therefore will not reply for that interrogation cycle. It will, however, be automatically picked up again on the next interrogation cycle, if voice communication is completed by then. Since most voice conversations are short, there is a high probability that any voice communication will occur between the interrogation cycles of a particular bus. Should an interrogation be missed, however, the storage capacity of the Elapsed Time Generator is great enough to maintain time until the next interrogation occurs.

Voice communication is originated in the bus by the driver removing his handset from its hang-up box and depressing the push-to-talk button. As stated earlier, whenever the handset is "off-hook," the radio is placed in the voice mode, and when the handset is replaced in the hang-up box, the radio returns to the data mode (Illus. 14).

An additional feature of the vehicle voice transmissions is that they automatically contain the vehicle address code, i.e., garage and run number. In the case of voice communication, the address is transmitted only at the beginning of each mobile transmission instead of repeatedly as in the alarm condition. The vehicle identification of voice messages appears on the digital readout display at the control center, and provides the dispatcher with a visual indication of the bus identity. Each vehicle identification is stored in the digital readout until replaced by the next incoming number. In the case of an alarm situation, the vehicle identification number of the bus is permanently stored until reset by the dispatcher. This assures that the identity of the vehicle will not be missed or lost.

Message spacing

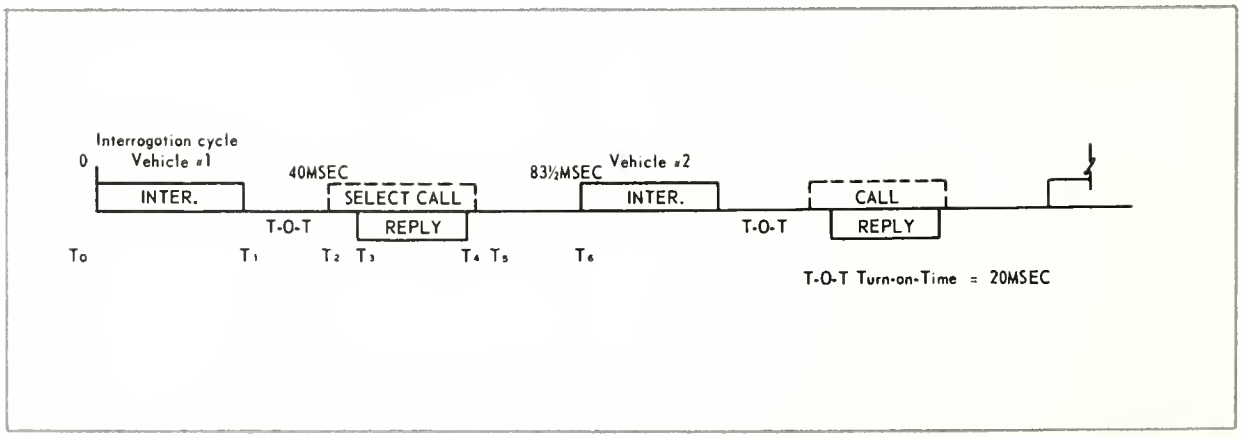


Figure 13

Voice radio handset

Illustration 14

Satellite receiver voting system

To provide adequate propagation coverage in the talk-back mode of operation from the buses, satellite receivers were employed. A total of three receiver sites are employed. The first, handling the central portion of the route structure was located at the same site as the base transmitters. Two additional sites, one to the north and one to the south were chosen to cover these areas.

Receiver voting is the process of electronically comparing and selecting the highest quieting levels of receivers operating on the same frequency but located at different points. By selecting only one receiver, the high noise and phase distortion which would result if several receiver audio lines were connected in parallel at the control center are eliminated.

Voting is accomplished by transforming a signal voltage from the receiver discriminator into discreet signal strength levels. These levels are used in the encoder to generate a tone, or combination of tones, which are sent with the audio from the receiver to a comparator. The comparator compares the incoming tone signals from several receiver-encoder combinations, and selects the receiver whose tone coding represents the strongest signal.

The encoder receives a signal from the receiver discriminator, and uses it to control two tone oscillators to generate a coded representation of the level within which the quieting figure of the receiver falls. This coding and the audio from the receiver are sent over wire lines to the associate comparator.

Three outputs are taken from the encoder; each is determined by the strength of the received signal. Very strong signals (level 3) cause only tone B to be generated; medium strength (level 2) signals cause tones A and B to be generated; weak (level 1) signals cause only tones A to be generated.

The tones are gated in such a way that a signal which does not break squelch will not gate through either tone, while a signal falling within the range of a level 1 will gate through tone A only, a signal within the range of level 2 will gate through both tones, and a level 3 signal will gate through tone B only.

When audio plus tone is received at the comparator via one of its channel inputs, it is applied to the tone decoders and to the audio gate.

The decoder outputs are fed to the input of the level priority gates, which compare the level of the signal being received by one channel with that of all others. These gates provide selection of the highest received level. Since several receivers may be receiving equally strong signals, several channels may give "highest level" indication. To avoid simultaneous selection, the lowest number channel is selected by a sequential priority gate provided in the comparator.

Once a channel is selected, it remains selected until another channel receives a higher level signal or a lower number channel receives a signal of the same level. When the channel is selected, its output is fed to the audio bus lines through notch filters to remove the coded tones before they are applied to the line output amplifier and transformer.

Block diagram of the data and voice channel receiver paths are shown in Illus. 15.

Extended capability

The bus and control center electronics may be easily expanded to incorporate additional monitor functions. Since the basic address format allows for up to thirteen additional forms of data retrieval (reference the 4 bit "system address" of Illus. 11), only the compatible electronics need to be added to the bus to accomplish this. In conjunction, a software change necessary to interpret the results would be required.

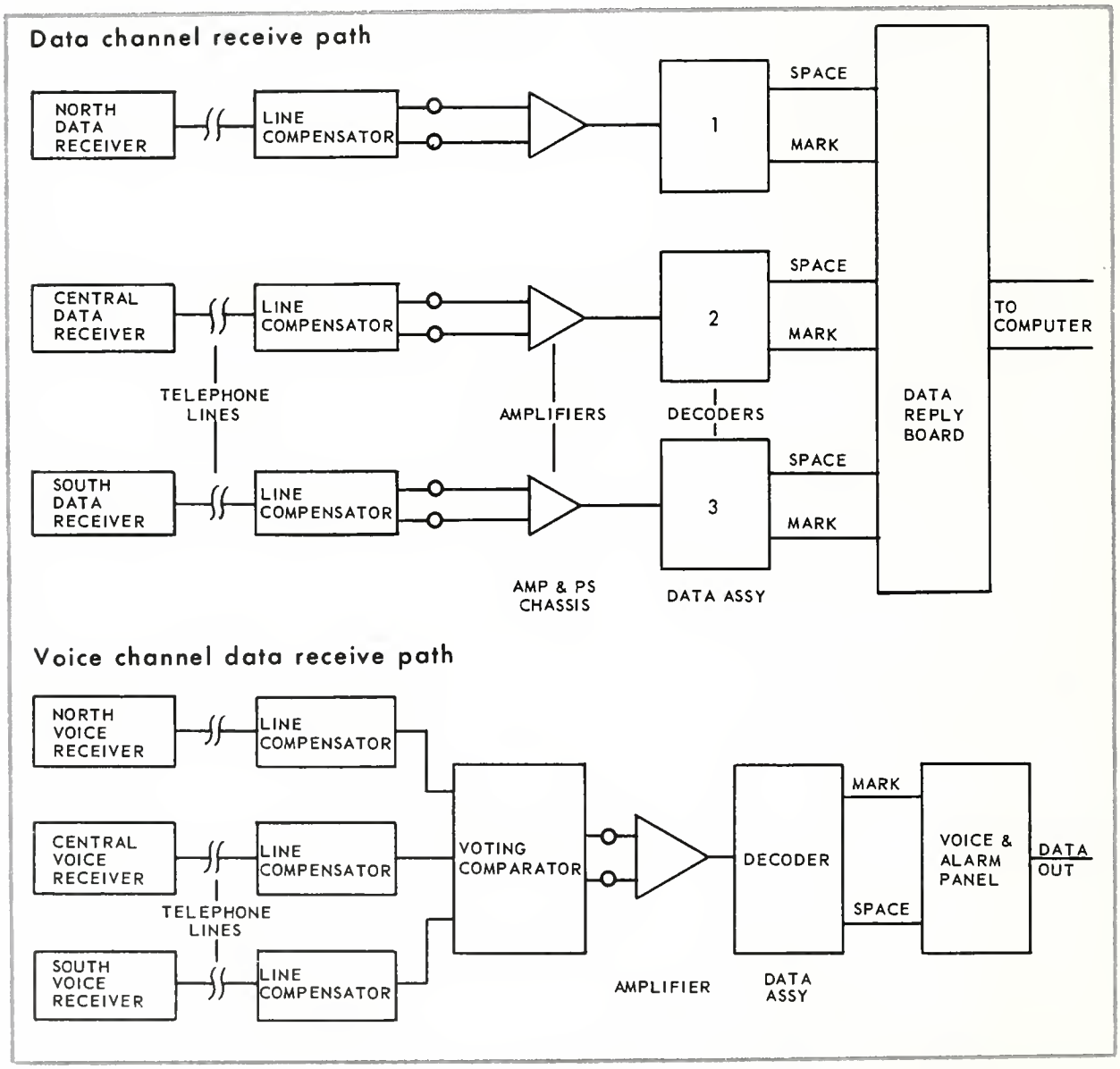


Illustration 15

SYSTEM DESIGN DESCRIPTION

Electronic signposts

Description

Electronic Signpost transmitters are placed at selected locations along fixed routes to furnish tone-coded location information to passing vehicles. These transmitters are continuous duty, low power units operating in the 150.8 to 162 MHz frequency range. They can be detected over only a short range (approximately 200 feet), thus preventing the possibility of a bus receiving conflicting location information from more than one signpost transmitter at a time or from a signpost transmitter not on its assigned route.

The encoding equipment continuously generates a preset 10-bit binary coded number for each location. The number's digital pulses are converted to tones for transmission by the signpost transmitter. Up to 1024 locations can be coded with this 10-bit system.

All equipment, including the integral antenna, is enclosed in one compact weatherproof housing. Mounting facilities are compatible with hardware on traffic signal controllers, poles and other standard signal devices (Fig. 1).

Signpost distribution

In order to obtain an accurate picture of the various mounting configurations for the signpost transmitters and to insure the availability of power, a location plan was devised. Keeping in mind the initial idea for full coverage of "owl services," 120 points were selected throughout the city. Each point was selected to cover two or more routes though sometimes only one was an "owl" route or a remote location had to be used to provide adequate coverage of a particular route. By taking this approach, it was assumed that the variety of routes providing "owl service" would yield a sufficient cross-section to test the system for daytime and rush-hour service.

The next consideration was given to spacing. This facet of the distribution was primarily controlled by the crossing of routes but it was attempted to maintain continuity and even intervals. Also, in keeping with the experimental nature of the project, it was decided to vary the intervals from route to route. This would provide guidelines in the future

Signpost transmitter performance specifications

RF OUTPUT	250 mW at 13.8 Volts dc
FREQUENCY STABILITY	±.0005% from –25°C to +75°C (28°C reference)
MODULATION	Type 8. 2F2, ±5 kHz for 100% modulation at 1000 Hz
CRYSTAL MULT.	9 times
SPURIOUS & HARMONICS	More than –46 dB below carrier
FM NOISE	At least 40 dB below ±3.3 kHz deviation at 1000 Hz
AUDIO DISTORTION	Less than 10% at 1000 Hz, 2/3 maximum rated deviation
TRANSMITTER FREQUENCY RANGE	150.8-162 MHz
PRIMARY INPUT VOLTAGE	117 Volts ac, 60 Hz
PRIMARY POWER INPUT	100 milliamperes
DIMENSIONS	9-1/8" high x 7-5/8" wide x 4-1/16" deep (not including mounting bushing)

Figure 1

for full system distribution. The overall average spacing of signposts for the routes covered is approximately two miles.

The sites were individually surveyed as to available power and desired coverage. It had to be determined that the geography of each location did not exceed the limits of the equipment and the desired coverage was achieved. Some of the more difficult locations were points along the expressways where one direction of traffic is on one frontage road and the other direction is on the other frontage road. Separation in these cases is up to 1/2 block (450 feet). At other locations the terminal for one route is 1/2 block to a block from the signpost to be used for both routes. To balance these difficult situations, however, a suitable number of intersections were selected which three or more routes passed through.

A system route map showing the distribution of signpost transmitters is shown in Illus. 16.

Signpost installation

The signpost installation presented no major difficulty once the position was determined (Illus. 17). Each unit was installed on top of a traffic light controller box. A simple modification involving most controller boxes "power loss indicator" was required. This is a red light mounted on top of the box which indicates that there was a power outage, the clock has stopped operating, and now, power has been returned but the lights were out of sequence with the city-wide pattern.

The lamp unit is screwed onto the controller box with a lock nut inside the box. By removing the light from atop the box and attaching it in a similar manner on the signpost housing, a threaded conduit from the bottom of the signpost could be used to mount the unit atop the controller box with no alterations. The Bureau of Electricity, who maintains the traffic lights, agreed to this plan.

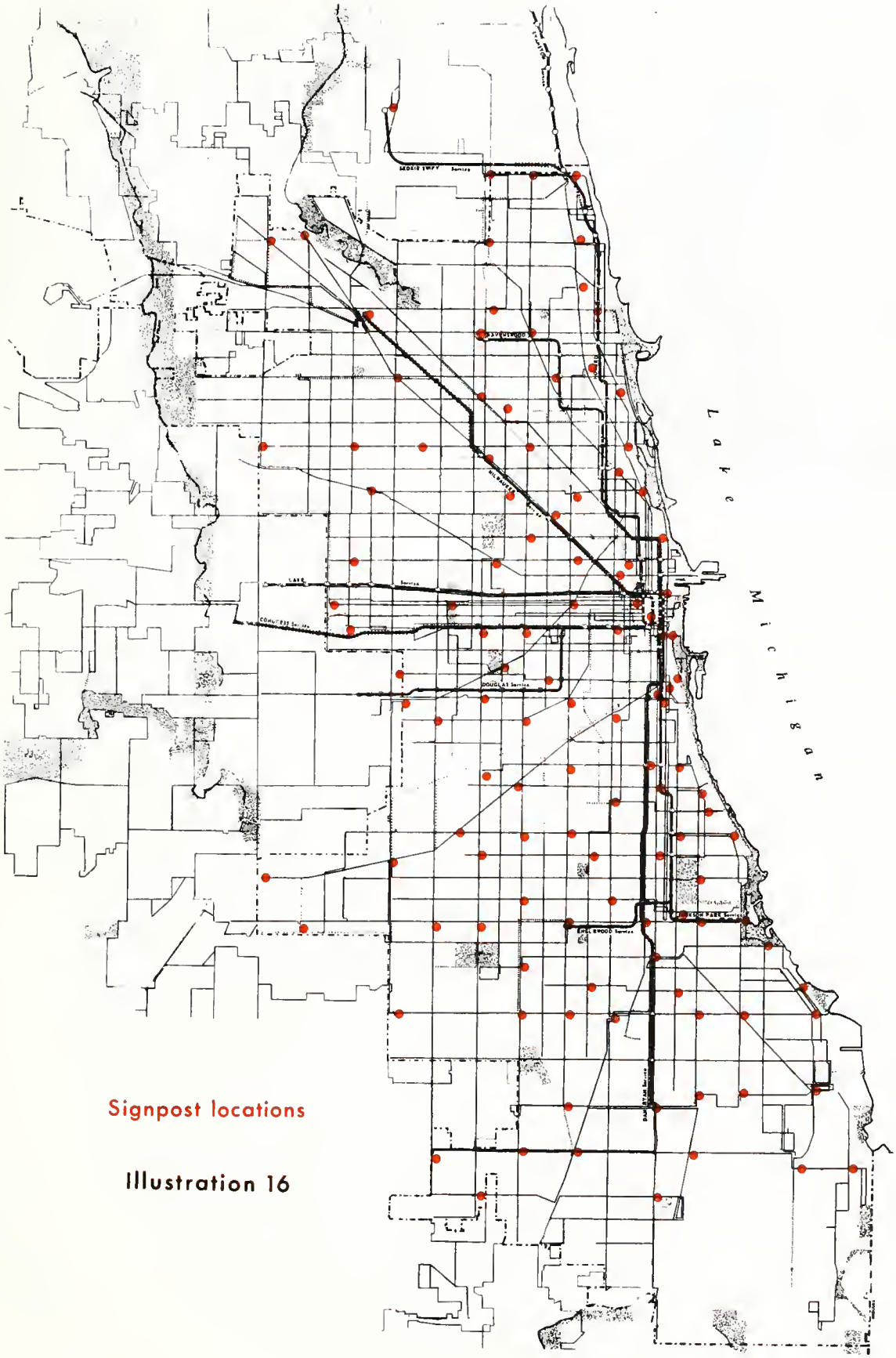
The City supplied the manufacturer spare light units to premount so that when the signposts arrived for installation, a minimum amount of work was necessary. The existing control wires for the light were disconnected and the unit removed. The signpost was screwed into place and secured; and the four wires, two for light control and two for signpost power, were connected. Once installed, the unit was turned on, final adjustments made, and left operating.

Problems encountered

Several problems occurred with the Signpost Transmitter equipment during the course of implementing the pilot project.

Lack of frequency stability in the tone oscillators used in the digital encoder caused variations in the ability of a bus to pick up valid signpost location data. Early in the program one cause of the frequency variations was traced to the effect of the r-f transmitter within the housing. A portion of r-f energy was radiating into the oscillator causing the frequency to shift. This was corrected by installing a metal plate as a shield between the audio tone oscillator circuit board and the low power r-f transmitter.

A second problem with the tone frequency, one not as easily recognizable, involving long-term frequency drift with both time and temperature. In some units, the basic frequency would drift out of tolerance over a period of months. The circuit was analyzed and several design changes made to replace capacitors in the oscillator circuit itself. These new components adjusted the design center of the oscillator frequency and were of a type exhibiting tighter tolerance characteristics on nominal capacitance and temperature.



Signpost locations

Illustration 16

Signpost installation

Illustration 17

All changes were subsequently implemented in the entire number of signpost transmitters used.

At one point in the program, the City of Chicago Traffic Department embarked on a program to re-paint all intersection controller boxes. Where signposts were installed, they were painted also. The painters used a lead base paint which effectively put a shield over the antenna located in the housing cover and caused the radiation of the r-f signal to drop, affecting the range of the signpost. The paint was subsequently removed and procedures instituted to prevent such occurrences in the future.

Repeated failure of a signpost unit at one particular location was traced to DC transients on the power line which would cause the power supply transformer to be destroyed. A blocking capacitor was placed in series with the input line, which corrected the problem.

The coverage range of the signpost transmitter was a significant factor in optimizing system performance. Actual r-f output of the units can be varied to accommodate the particular site it is located at. Initially, the output was set to a nominal r-f output measurement. This did not prove satisfactory in all cases because of variations in the antenna system located in the housing cover, radiation pattern, mounting particulars, etc. Cases of both insufficient and excessive signal levels resulted. A field strength meter was utilized by the contractor to help solve the problem. Signpost range is set by adjusting the r-f output of the transmitter to provide a given r-f signal strength at the desired distance from the position of the unit. Additionally, a circuit change was made in the transmitter output circuit to allow adjustments down to a few milliwatts, i.e., the overall range of power output adjustment was increased to accommodate various installations.

Bus radio

The bus mounted Data Retrieval Package a solid-state 450-470 MHz FM Two-Way Radio Unit with eight channel capacity for voice and data flow, and a Supervisory Unit for processing the data (Illus. 18).

Specifications for the Bus Radio Unit are as follows:

The radio unit portion of the data retrieval package is a fully transistorized FM two-way unit which utilizes the advantage of solid-state, circuits--low current drain, reliability, small size, ruggedness, and low maintenance requirements. No tubes or relays are used in the entire radio unit and no high voltage power supply is required because the highest voltage required is available directly from a 13.6 volt vehicle battery. Unheated, temperature-compensated, plug-in crystal oscillator modules (channel elements) are used for frequency control. The same channel element supplies the stable oscillator frequency for both the transmitter and receiver for any particular channel. 5.00 MHz separates the transmit and receive carrier frequencies on each channel. Up to eight channel elements may be used, which provides for up to eight channels of operation.

Transmitter

The solid-state FM transmitter provides 20 watts of continuous duty r-f power. Circuits include a temperature-compensated crystal controlled oscillator module (channel element) for each operating frequency, audio amplifier and IDC (Instantaneous Deviation Control) circuit, varactor phase modulator, completely transistorized exciter and power amplifiers, and a varactor tripler. Frequency multiplication in the exciter, power amplifier, and the varactor tripler produce an output frequency 24 times the crystal frequency. A high level of spurious frequency attenuation is achieved in a harmonic filter at the transmitter output. A cavity-type antenna coupler circuit provides isolation between the transmitter and receiver and eliminates the need for antenna switching (Fig. 2).

Receiver

A completely solid-state, crystal controlled dual-conversion receiver provides audio power for the Control Unit handset. R-f preselectors (tuned cavities) and a sealed filter in the r-f stages determine the excellent bandwidth and selectivity characteristic of the receiver. Noise is eliminated when no messages are being received by noise-actuated (carrier) squelch circuitry.

Supervisory unit

The completely solid-state supervisory unit contains the squelch circuit for the radio unit and the data processing equipment. The data processing boards include a high speed encoder, high speed decoder, location storage, interrogation, interface, and power supply mounted on a fold-out chassis.

Housing

The circuits of the basic radio and supervisory unit are assembled to form a drawer unit which slides into the housing. A key lock secures the data retrieval package in the housing. Part of the front panel becomes a carrying handle.

Bus radio with foldout supervisory unit

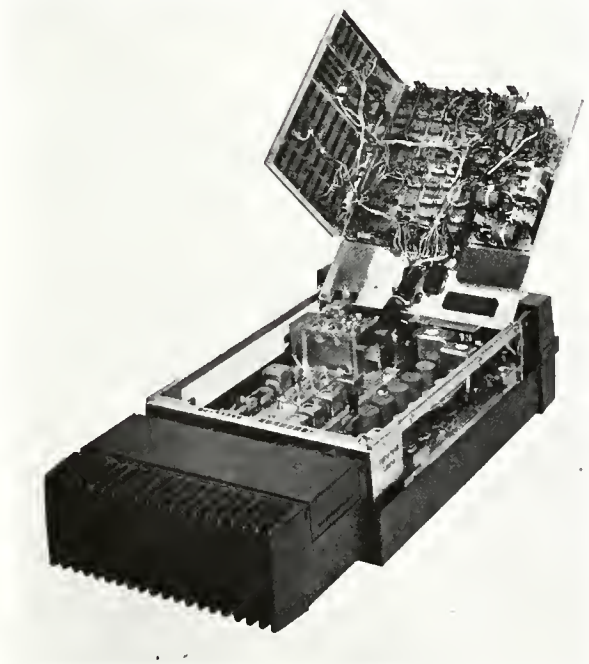


Illustration 18

Bus radio performance specifications

GENERAL

Input Voltage	±13.6V dc
Battery Drain	standby - 2 amps maximum transmit - 10.0 amps average
Dimensions	radio without mounting rack - 11" w x 22-1/2" d x 5" h.
Weight	45 pounds (approx)
Maximum Channel Spacing	500 kHz
Metering	Motorola portable test set can be used to measure all radio circuits essential to tuning and checking through central metering plug. (A single scale, 0-50 uA meter can also be used)
Power Supply	None
Frequency Channels	450-470 MHz (maximum of 4 channels)
Operating Temperature	-30 C to +70 C

TRANSMITTER

Minimum RF Power Output	20 watts
Output Impedance	50 ohms
Conducted Spurious Harmonic Emissions	more than 90 dB below carrier
Audio Distortion	less than 5% @ 1000 Hz ±3.3 kHz deviation
Frequency Stability	±0.00035% of assigned carrier frequency from -30 C to +60 C ambient (+25 C reference)
Audio Response	+1, -3 dB of 6 dB/octave pre-emphasis characteristic from 300-3000 Hz
Modulation	15F2 & 16F3 +5 kHz for 100% @ 1000 Hz
FM Noise	60 dB below ±3.3 kHz deviation
Duty Cycle	continuous

RECEIVER

Channel Spacing	25 kHz
Selectivity	(20 dB tone-to-noise): -100 dB @ ±15 kHz (EIA): -85 dB @ ±25 kHz
Modulation Acceptance	±7 kHz
Sensitivity	(20 dB tone-to-noise): 0.7 microvolt (EIA): 0.5 microvolt
Frequency Stability	±0.00035% of reference frequency from -30 C to +60 C ambient (+25 C reference)
Spurious & Image Rejection	more than 100 dB
Intermodulation	-80 dB
RF Input Impedance	Nominal 50 ohms

Figure 2

The housing mounts in a convenient location in the vehicle and is controlled by a separately-mounted control unit (Illus. 18). All connections are made to receptacles on the front panel. The entire data retrieval package can be quickly removed from the housing and replaced with another unit in fleet operations.

When removed from the housing, a hinged modular mounting plate can be lifted for access to most circuits. Finned heat sinks radiate the heat from the high power transistors. No venting of the housing is necessary, so components are protected from dust and contaminants.

Control unit

The Control Unit provides the control facilities for the Data Retrieval Package. The control unit contains a 153.740 MHz receiver that receives tone encoded fixed location information from Electronic Signposts. The Antenna for the receiver and a Handset with a push-to-talk switch for voice communications are part of the control unit package (Fig. 3).

The control unit also has the following features:

Two-Channel Operation -- A two channel selection switch and illuminated channel selected indicator lamps for controlling the 450-470 MHz radio in the data retrieval package. This switch controls the selection of the voice channel only and has no effect on data channel operation. Since only one voice channel is utilized in the pilot system, the switch is inoperative and the unit jumpered for single voice channel operation.

Alert -- An audible signal warning device alerts the vehicle operator to incoming calls.

Transmit Indicator -- A transmit indicator lamp is provided for normal voice communications. The lamp does not illuminate on alarm transmissions.

Alarm -- The control unit is connected to a concealed switch. Pressing the switch initiates a preset alarm transmission in the data retrieval package.

Control unit performance specifications

GENERAL	
Input Voltage	13.8 V dc
Operating Temperature	-30 C to +60 C
Dimensions	10-3/16" high x 9-1/2" wide x 4-1/4" deep
RECEIVER	
Operating Frequency	153.740 MHz
Sensitivity	10 microvolts for consistent error free data output
Spurious & Image Rejection	More than 40 dB from carrier reference measured when receiver is matched to 50 ohms
Selectivity	50 dB minimum from carrier reference at ±30 kHz
Deviation	±2 kHz
Frequency Stability	±0.002, -30 C to +60 C ambient (+25 C reference)
Spurious Emissions	Meets FCC specifications pertaining to emission per FCC Rules, Part 15, Subpart C, Section 15.6. All radiated spurious emissions falling within commercial television frequency bands will not exceed 75 microvolts measured at a distance of 10 feet from the receiver at a height of 7 feet above ground. The test environment is defined in EIA Standard RS-152-A, dated October, 1959 in Section 4.3.1 under Radiated Spurious Emission.
TONE DECODER	
Operating Frequency	Mark Input: 2200 Hz Space Input: 1200 Hz
Outputs	Mark or Space negative pulses.

Figure 3

Run Number Thumbwheel Switch -- This three digit switch allows the operator to manually set his run number prior to initiating each vehicle run (Illus. 19).

Thumbwheel switch

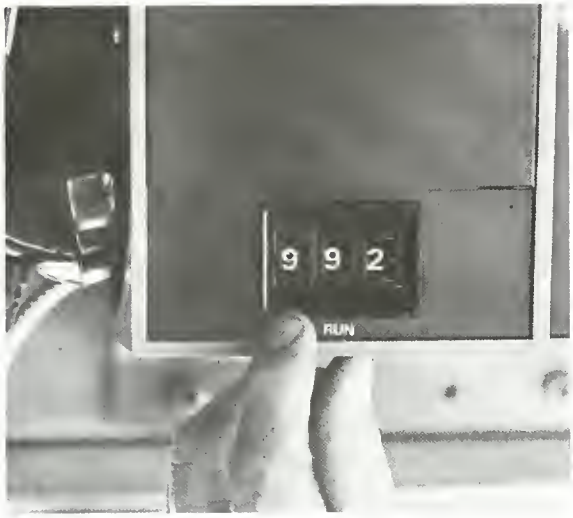


Illustration 19

Bus radio installation

The Technical Services Division of the CTA determined the placement of the material on board the buses. The radio package itself, as described previously, is enclosed in a locked, weatherproof, water-resistant case. This unit is easily removable for maintenance due to the permanently mounted, locking rack which the unit sets on. The radio unit is slid into place on the rack, locked in and plugged in; it is then ready to operate. The key for the base lock is different from the key for the case lock providing double security.

A position behind the operator's seat and extending under the passenger seat was selected (Illus. 20). The base was placed so that the floor under the unit might be swept or washed with no difficulty or fear of damage. The unit also had to be installed low enough to allow easy removal and not to interfere with the mobility of the operator's seat. This location was also convenient to the power panel where the connections would be made to the electrical system and near a point where the cable from antenna on the roof could be accessed quite easily.

It was necessary to make test installations on each type of bus to determine the hardware necessary to use this location. As each series of buses was worked on, the control head position was determined and the hardware necessary for the installation specified.

Bus radio antenna

The antenna installation on the buses utilized a vehicular type "whip" antenna mounted on the centerline of the roof approximately 5 feet from the front of the bus. This antenna operated satisfactorily from an electrical standpoint, providing acceptable "talkback" coverage throughout the system and achieving optimum reception of data and voice communications emanating from the base station transmitter.

During the initial months of operation it was discovered that movement of the buses through washing facilities at the garage locations was causing the antennas to be bent back at an angle. Although causing no electrical problems and having no effect on propogation characteristics, the malformation of the antennas did cause a definite appearance problem (Illus. 21).

Several different modifications were tried on the basic whip antenna in an attempt to provide a design which would be less affected by the bus washing equipment. In general, though, it was

Mobile radio installation

Illustration 20

felt a rigid type antenna would be the only satisfactory solution to the problem.

Damaged whip antenna

Illustration 21

The final choice was a rugged, heavy duty design with the radiating element enclosed in a fiberglass radome (Illus. 22). Repeated tests through the various types of wash racks employed by CTA were made and showed this antenna to be impervious to damage from the washing equipment. In addition, the thin, smooth design provided a satisfactory appearance.

Bus environment

The environment of an urban transit bus, both from a mechanical and electrical viewpoint is quite different from that found in normal vehicular two-way radio installations. In addition, the effects on digital logic circuitry by extraneous electrical interference became a factor to be reckoned with. Various types of interference which may not affect normal voice communications must be suppressed to avoid adverse effects on data communications.

During the prototype installation phase, it was found that a filter was required in the A+ power lead to suppress various electrical noise interference and avoid any effects on the digital logic circuitry. This becomes a part of every bus installation.

On buses utilizing a particular type of high voltage power supply for the flourescent lighting, an additional filter network was required to suppress further electrical interference from this source.

Once the bus radio equipment was installed, further testing of bus radio performance showed still further difficulties. In some cases, false alarm messages were being initiated; the switch was not activated, but an alarm was transmitted. In another case, occurrences arose whereby an interrogated bus replied with a data message which decoded properly, yet the signpost number did not match any number in the system. Both of these problems were found to originate on the buses with the same cause, electrical noise. In this case, it was found that some of the solenoids on the bus caused very large transients to appear on the power lines when they were operated; these transients were so large that the previously installed A+ filter was not sufficient to suppress the resulting energy. As a result, the information in the location storage registers was destroyed and/or the alarm control circuit was triggered.

Capacitive and diode suppression devices were installed in the solenoid circuits and the problems corrected.

Enclosed antenna

Illustration 22

These particular problem areas are pointed out here to emphasize the special nature of two-way radio installations on board transit coaches. The environment the radio encounters is quite different from an automobile installation. Special precautions must be taken to assure adequate filtering is a part of every installation and avoid the harmful effects which electrical interference can have on the total communications system. Any specification issued by a transit property for procurement of data and voice radio equipment should clearly define the need for adequate filters and suppression devices to avoid difficulties in achieving reliable system operation.

Bus radio equipment - problems encountered

A number of hardware problems were encountered with the bus mounted equipment; some were the result of the equipment design, others derived from the unique environment of the transit bus, and several additional ones arose from the human aspect of the personnel using the equipment. Previous sections addressed themselves to two specific areas, the bus electrical environment and the bus antenna. A brief synopsis of the remainder follows: All problem areas were thoroughly investigated and subsequent changes implemented to correct the malfunctions.

-An early problem involved a failure mode of the logic package which resulted in continuous keying of the transmitter. This "tied up" the system until the unit was found. A time-out-timer was added which opened the transmitter keying circuit after 90 seconds of continuous transmit condition.

-As discussed previously, the bus electrical system itself had an effect on the overall operation of the logic package. To counter and overcome these adverse situations, filtering was added in the A+ power leads to reduce ripple caused by alternator whine and fluorescent light power supply as well as transients introduced by the hand brake. Some buses required additional suppression on brake and door solenoids. Resistance type ignition wiring was installed on propane buses.

-The installation of the alarm switch allowed infiltration by water. Since the switch was in a high impedance circuit, the moisture effect could cause false activation of the alarm mode. An interposing relay was added to overcome this situation.

-The frequency selection switch on the control unit proved susceptible to damage. A rotary switch had originally been installed and high torque exerted on the knob could fracture the switch mechanism. An extremely heavy duty, push-button switch replaced the rotary type and corrected the problem (Illus. 23).

Control head with rotary channel selector

Illustration 23

-The antenna for the location receiver is a short length of rubber coated heliax which hangs from the bottom of the control unit. This proved to be a convenient handle for drivers to use when getting out of their seat. Over time, this stress caused the antenna to stretch, eventually to an intolerable length. All antennas were replaced with a heavier gauge heliax which would not

stretch to overcome this problem.

-Control head hook switches, used to revert from the data channel to the voice channel, would stick in the closed mode preventing the unit from switching to the voice channel when the handset was removed from its hang-up facility. An improved version of the switch was installed on all units to correct this failure mode.
-The screw used to secure the two halves of the control head, originally a standard phillips head type, was replaced with a special "spanner" type to prevent unauthorized tampering with the circuits inside the control head. Special tools compatible with the unique screw head are now required.
-In the logic unit itself, the initialization circuit was modified so the unit, upon initial turn-on, would always come up on the data channel whether the handset was on-hook or off-hook

-Some units were found to be "over zealous," i.e., a unit would initiate a data reply when it was not interrogated. Circuit changes were implemented to correct this. The difficulties resulted from a variety of sources. The troubles were traced to various component failures and "cold solder" connections and corrected.
-So called "random reply" units would initiate a data reply when the unit was turned "off," then "on" again. A particular transistor type in the power supply regulator circuit proved prone to intermittents causing these failure modes. Circuit design changes were implemented and the transistor type changed.

-Under certain conditions, a unit would reply with erroneous location data, i.e., an "invalid signpost number." Circuit design changes were made to correct this problem. Instability in the phase delay of phone lines to the system's satellite receivers caused the false location information to appear. Circuitry was designed to compensate for the instability.

-Erratic timers in mobile units caused variations in the accuracy of the elapsed time which is a part of the location data reply (signpost number plus elapsed time). The circuit was redesigned to provide greater stability over time and temperature variations, eliminating this problem.

Base stations

Central station equipment

The base station radios are high power, two-way FM base stations housed in compact cabinets. The stations operate in the 450 - 470 MHz frequency range with a continuous duty r-f output of 90 watts. All stations require 50/60 Hz, 117 - volt AC power.

These stations employ completely transistorized receivers, exciters, power supplies and control units. Only the power amplifier stage in the transmitter uses a tube. The advantages of the transistor--low current requirements, reliability, light weight, compact size and low maintenance requirements--are fully utilized. Solid-state switching replaces all relays except the antenna relay. Current demands are low, and unheated temperature compensated, plug-in oscillator modules (channel elements) are used for frequency control. In addition, blowers and their related maintenance problems are eliminated by the use of heat sinks in the transmitter amplifier stages.

The station cabinets are of rugged steel construction with front and rear door and are easily removed for servicing. The compact cabinet size per-

mits shelf mounting in addition to the standard floor mounting.

The station is constructed so that all metering controls are accessible without interrupting communications. There is no interlock on the front door since there are no high voltages present on the front panels. Switches are provided for placing the station under local control while servicing.

Remote control facilities

These stations contain a transistorized remote control chassis which is used in conjunction with a control console to provide the specific switching functions required for operation of the station. Control of the station functions from a remote point is accomplished by applying various DC line currents to the remote control chassis via the control line from the control console.

Description of items

-Receiver

The completely transistorized receivers in these stations are crystal-controlled, dual conversion models. R-f preselectors, an i-f (Intermediate Frequency) crystal filter with a sealed filter in the i-f stages determine the bandwidth and selectivity characteristics of the receivers. Temperature compensated, plug-in crystal oscillator modules (channel elements) provide excellent frequency stability without the use of a crystal oven. The channel elements are two-piece units in which the upper (resonator) portion plugs into the lower (oscillator) portion. The frequency can be changed by unplugging the resonator and replacing it with one of a different frequency. Disturbing noise during periods when no messages are being received is eliminated by noise actuated squelch circuitry.

-Exciter-Transmitter

The exciter-transmitter is completely transistorized. Channel elements furnish the fundamental transmitter frequency. Modulation is effected by a varactor phase modulator and low distortion "Instantaneous Deviation Control" circuit which provides modulation with a very low distortion level. The output frequency of the exciter-transmitter is 36 times the crystal frequency. A harmonic filter at the output of the exciter-transmitter attenuates all frequencies outside the 450 to 470 MHz band. The exciter-transmitter is used to drive the power amplifier.

-Power Amplifier

The power amplifier is a one-tube tetrode amplifier which increases the r-f output from the exciter-transmitter to the rated power output of the station. It is a separate unit, incorporating its own high voltage plate, screen, and grid bias supplies. A low-pass r-f filter at the power amplifier output suppresses all frequencies above 470 MHz. A metering receptacle is also located on the power amplifier panel.

-Power Supply

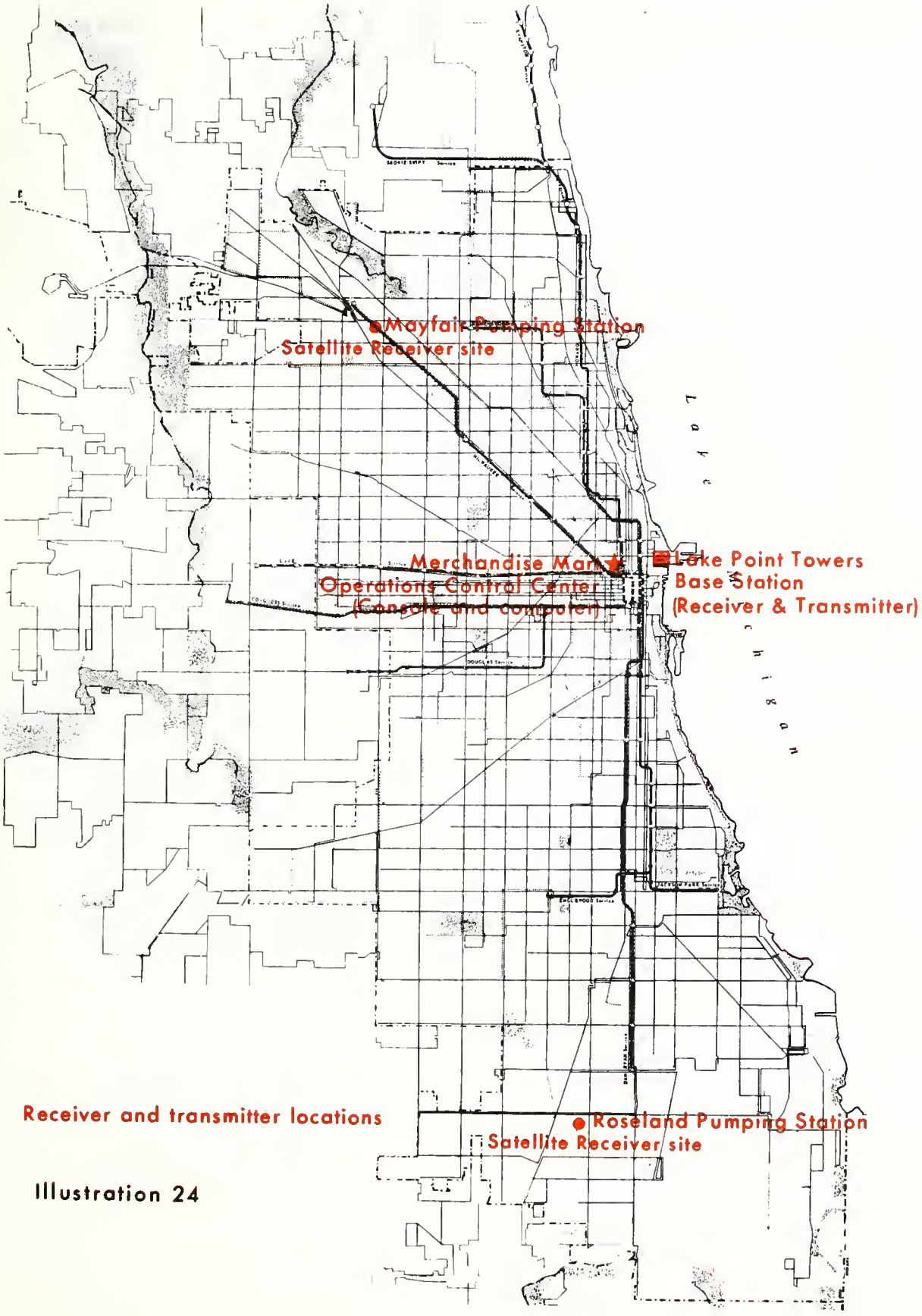
The power supply provides all the voltages necessary for operating the station, except the operating voltages for the power amplifier.

-Remote Control Unit

The station contains a solid-state, modular Remote Control Unit. The unit performs station control functions such as transmitter keying in response to DC currents from the remote control point. It also provides a panel for local testing and operation. The unit consists of a wrap-around chassis which interconnects a number of plug-in modules. The plug-in modules speed maintenance and trouble-shooting.

-Power and Audio Line Junction Box

The junction box is provided as a convenient means of connecting the 117-volt AC line and the control lines used for remote operation of the station. An



Receiver and transmitter locations

Illustration 24

AC receptacle and the main station fuse are also located on this box.

Antenna site location

A propagation study was performed to determine the best location for the base station transmitters (both data channel and voice channel). It has been anticipated that several additional receiver sites (satellites) would be required to optimize "talk-back" coverage from the bus radios.

Following the propagation study, site surveys were taken to determine what specific locations might be available for antenna locations.

The location chosen for the base station transmitters and central satellite receivers was Lake Point Towers, a 70 story apartment building on the Lake Michigan shorelines, just north of the downtown area. Two additional satellite receiver sites were chosen, one to the south with the antenna atop a chimney at the Roseland Water Pumping Station and a second to the north on a similar structure at the Mayfair Water Pumping Station. The relative positions of the various locations are illustrated on the system map, Illus. 24.

In the installation and initial system testing stages of the system a problem arose with the satellite receiver system caused by interference between the voting tones and the tone frequencies employed in the data transmissions. With the voting tones and the data tones on the same telephone line pair, the tones would mix and cause improper decoding of the data messages. To solve this problem, the frequencies of the voting tones were changed to values where the result of the mixing would not interfere with the data.

Telephone lines

The base station transmitters, data and voice, are controlled from the communication center via telephone line pairs. Similarly, the satellite receivers are connected to the center by telephone lines. This is common practice in communication systems where remote location of transmitters and receivers become necessary.

While normal voice communications pose no particular problems with this type of operation, the introduction of high speed digital data communications as used in the Monitor CTA system brought out an unanticipated problem with the telephone line circuits used to control the data channel transmitter and satellite receivers.

A necessary characteristic of the phone lines is a linear phase delay in the audio range. On some lines there may be minor variations which can be corrected with the addition of circuit components. With these corrections instituted on the phone lines to Lake Point Towers, operations from this location became very consistent. When these changes were made to the South side satellite receiver, no change of accuracy in the data transmission was noticed. Closer investigation revealed that these phone lines were not in conformance with specifications. Discussions with Illinois Bell Telephone Company (IBT) confirmed that the lines supplied did not meet the necessary qualifications and, furthermore, it was questionable that the telephone company could supply this type of line. After additional negotiations and clarifications, it was determined that these lines could be supplied and the necessary orders were placed. After the South lines were found to be unsatisfactory, all the other telephone lines were tested. The north lines were also unacceptable and though the lines to Lake Point Towers had the same characteristics, the shorter distance made them more acceptable.

The supplying of more suitable telephone lines by IBT did not fully solve the problem of inconsistent data trans-

mission, over the wires. There still existed the problem of phase stability, line equalization and level setting consistencies. Although these could be set properly by maintenance personnel, it was readily noted to be an involved procedure and one which had to be repeated periodically.

The final solution was found in the implementation of specially designed compensation networks employing phase lock loop circuitry. This provided solutions to two basic problems with the telephone circuits. First, it compensates for better phase response over the telephone line and optimizes the integrity of the data messages moving over the line. Secondly, the circuitry used is relatively insensitive to changes in signal level, i.e., the dynamic range increased to the point where level setting ceased to be a critical procedure. This eliminated the need for repeated checking and adjustments by the maintenance personnel.

Communication control center

The Communications Control Center consists of two identically equipped desk type control consoles which form the complete control and monitoring facilities for the Monitor-CTA system (Illus. 25). It provides selection and gating of the automatic interrogation transmissions, selective calling equipment and associated gating circuitry, control of data transmissions, both from an associated computer (for location interrogations) and from the selective calling equipment. The control center includes all electronic circuitry necessary for the decoding and display of information from voice and emergency transmissions received at the control console.

Communication control center

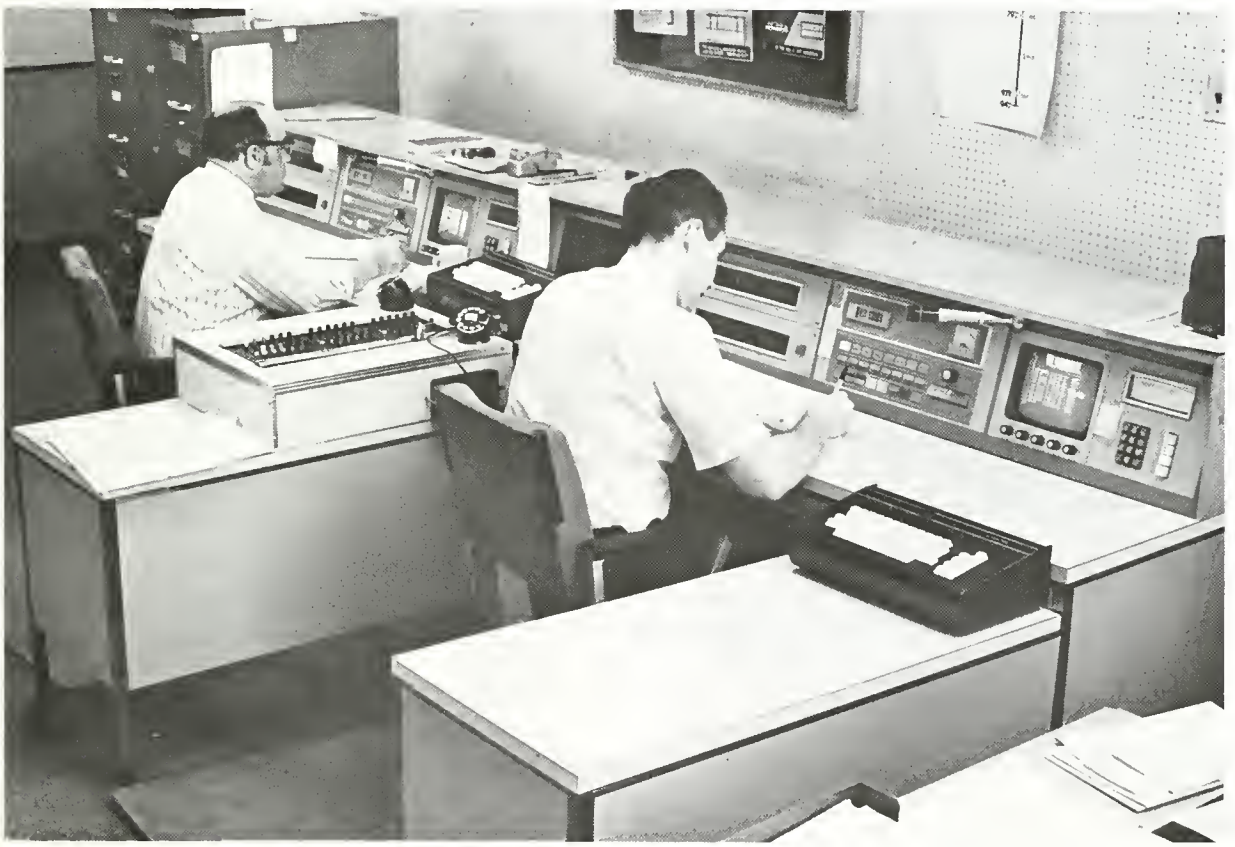


Illustration 25

With regard to the basic data interrogations of vehicles for schedule adherence purposes, the information returned from the vehicle is processed within the computer complex. The computer analyzes and displays the information upon a cathode-ray tube (CRT) monitor in the console.

Alarm notification from any vehicle under the system control is displayed in two forms at the console. Upon receipt of an alarm, the vehicle identification is processed by the computer and complete information data including route and run number and location is displayed on the face of the CRT. In addition, garage, run and signpost numbers are displayed on a numerical readout device at the console. A light flashes and an audible warning device sounds to alert the dispatcher to the call for help.

Voice communication to any single vehicle, or group of vehicles, is controlled from the operating console. Selective calling control is available on the console whereby the dispatcher presses a series of buttons on the console to select the desired vehicle identification number, or group number. These buttons are labeled 0 through 9, INDIVIDUAL CALL, AND GROUP CALL. A CANCEL button is also provided to clear the selection before the call is initiated by one of the CALL buttons (Illus. 26). As the identification numbers are selected, they appear on numerical readout devices in the console panels. Voice communication between the console operator and the vehicle is available via the console microphone and speakers.

Computer interface cabinet

The Computer Interface Cabinet contains the electronic circuitry necessary to connect the digital computer to the communications control center console. The equipment provides the interface for data transmission and reception from and to the computer.

Selective call panel

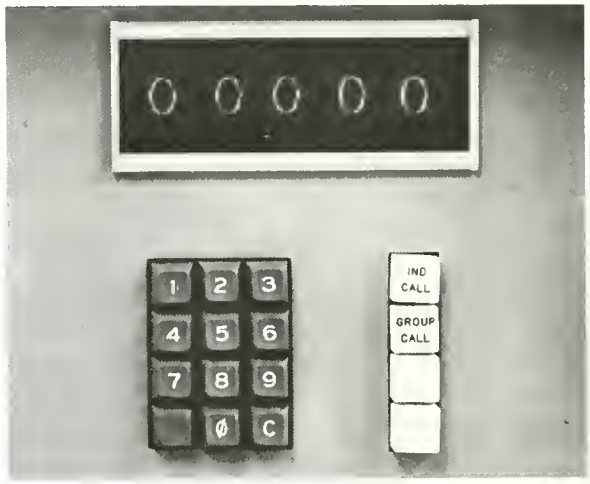


Illustration 26

The interface cabinet accepts location interrogations from the computer in parallel form. This digital information is restructured to transmit portions twice, then converted to audio tones for the actual transmission.

Information from the data receivers is converted from audio to digital form for presentation to the computer.

The overall equipment complement includes the following:

The Data Reply Channel Module contains logic circuitry to verify vehicle location data received for accuracy. After verification, the data is presented to the computer.

The Power Supply furnishes regulated operating voltages to all equipment in the interface cabinet except the data amplifiers.

The Cable Kit and Termination Panel includes all interconnecting wiring between units in the cabinet and the termination panel. The termination panel provides terminal lugs for making external connections to the interface cabinet.

The Cabinet is a 42 inch high metal enclosure with front and rear access doors. It houses the electronic equipment and is intended for indoor use.

The Amplifier and Power Supply Assembly contains the data amplifiers and a power supply. The data amplifiers

provide separate amplification of each line to a data receiver, and another amplifier for the data transmitter.

The Data Receiver Assembly contains high-speed encoders and decoders for conversion of digital information to audio and vice versa. It also provides the mounting for the computer interface portion of the data interrogate channel.

Computer hardware

The computer used in this project is a process automation computer (Illus. 27).

Peripheral devices used in the system are a card reader, paper tape punch, paper tape reader, teletype, data link, two CRT displays controlled through a magnetic disc memory, AU channel output, and digital input channels. The first five devices are for programmer communication with the computer. The card reader is the primary program input device; programs, once written, will be punched on cards to be read by the compiler, a program which translates user programs into a "language" understandable by the computer.

As explained previously, process computers do not handle a large amount of input data; therefore, the card reader operates at only 100 cards per minute while card readers for business computers operate at 900 to 1200 cards per minute. The card reader is also used for some data input.

The paper tape punch is used by the compiler to record the machine language programs and as an auxiliary data output device. The paper tape reader is for loading the functional, machine language programs into the system; it can also be used for data input.

The teletype is used for programmer communication with the operating system for loading, debugging and manual control; it is also used for some of the operating logging (Illus. 28).

The data link is the major data input/output device; it connects the process computer with CTA's existing business computer and high speed peripherals. Using this link, data from

Monitor's process computer

Illustration 27

Teletype printout

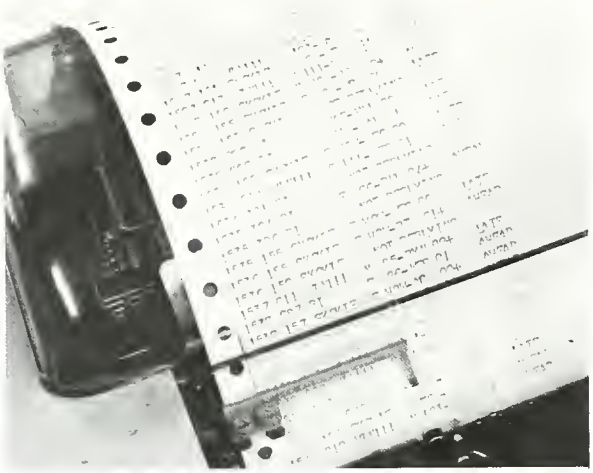


Illustration 28

operations can be transferred to the business unit, printed on a 1200 line per minute printer, and stored on magnetic tape. Also schedule data, which would take 35 minutes or more to read on the process computer, can be read in 3 minutes or less on the business computer using cards or magnetic tapes, peripherals not present on the smaller unit (Illus. 29).

The CRTs are for display of off schedule information, alarm messages and dispatcher communication with the data system. Data requests by the dispatcher are handled by a series of special functional programs turned on by the dispatcher from the display input keyboard. The dispatcher calls for the type of data he desires; the computer displays a questionnaire to request information necessary to find the desired data, and then returns the data.

The magnetic disc is a bulk memory device used to store all functional programs, the schedule file and operations history. It has 1,000,000 words of random access storage. By knowing where a piece of data is located on disc, a request for that data would go immediately to that point instead of searching through part of a reel of tape or a deck of cards. Since the computer has only 12K, approximately 12,000 words, of core memory, and RTMOS (Real Time Multiprogramming Operating System) and common data areas takes about half of this, there is not sufficient room in the core for all the functional programs. This means that RTMOS, once it determines if a program is to run, checks if the program is in core; if not, the program must be transferred from bulk. After the request for transfer is complete, a special interrupt is generated which causes RTMOS to be entered and the program list searched from the beginning. This is a check to determine if the program just transferred from bulk is more important than the one running.

Computer software system description

The software system consists of many small specialized programs which operate under the control of the standard process computer RTMOS. This approach makes most efficient use of the operating system while simplifying program maintenance and debugging. These programs are:

- -System Initialization
- -Location - Status
- -Interrogation Driver
- -CRT Output
- -Alarm Driver
- -Alarm Decoder
- -Keyboard Input
- -Tolerance Change
- -Run Status Change
- -Demand Interrogation

SYSTEM INITIALIZATION is the first program to operate when the system is turned on. It is turned on from the dispatcher's CRT (Cathode Ray Tube) keyboard by means of the Keyboard Input program. It is used to turn on and turn off the monitoring system. This program performs the following turn on functions:

CTA's business computer

Illustration 29

-Calculates a system turn on time (The dispatcher can specify that the system be turned on immediately or any time within 24 hours of the present time.)

-Initializes all system constants and schedule file control fields.

-Initializes the Interrogation Driver. (A driver is a small program which controls external devices or executes other programs.)

-Turns on the Location - Status program.

Once the system is turned on by this program, it will operate indefinitely until it is turned off by the dispatcher requesting the operation of this program in the turn off mode. The program performs the following turn off functions:

-Turns off the Interrogation driver.

-Sets a flag for Location Status to turn off.

-Prints out a brief summary of the system's operation during the previous turn on period.

This initialization program allows the radio dispatcher to start the Monitor programs from a remote location (control center). In this way it essentially eliminates the necessity of a computer operator.

LOCATION - STATUS is the largest and most important program in the system. By performing the following functions it creates the work for the other programs:

-Transfers segments of the schedule file from bulk to core for processing.

-Determines which vehicles are currently operating and loads their address output list (data buffer).

-Removes vehicle replies from the reply input list and determines schedule status.

-Calculates a vehicle's deviation from schedule and compares this to stored tolerances.

-If a vehicle is out of tolerance, the necessary information is stored in the CRT output list and the CRT Output Program is turned on.

-Finally, after all the work has been completed on a segment of the schedule file, it is transferred back to bulk with the necessary tracking data updated.

-Responses from all interrogations are stored on bulk storage for future processing.

This program is set to run at fixed intervals. It will interrogate all of the vehicles in the system each cycle. If it

has taken longer than the interval time to complete the interrogation, it will immediately begin the next cycle; otherwise, it will delay itself.

Because of the size of this program and the large segments of the schedule file with which it works, it is most important that it uses a minimum amount of computer time when it operates. The most time consuming computer operations are input and output calls to business peripherals. Location - Status does not make any of these calls. Therefore, it essentially operates at "computation speed."

However, it was necessary for Location - Status to make several bulk transfers. Although bulk transfers are not nearly as time consuming as input/output calls, they do take considerably more time than instruction execution time. Anytime that a program is in core waiting on a bulk transfer, it is inefficient. This program uses a method of flip-flopping between segments of the schedule file to eliminate this "dead" time. It has two large buffers for schedule data. While it is operating on the data in one buffer, it is transferring data to and from the other buffer.

INTERROGATION DRIVER is the software interface between the "location" hardware and the computer. It operates at a fixed interval (every 83 1/3 milliseconds) and performs the following functions:

-Inputs the response from the last interrogation and stores it in the reply input list for Location - Status to process.

-Outputs the identification number of the next vehicle, which is to be interrogated, to the Computer Interface. It obtains these numbers from the address output list which is filled by Location - Status.

-Provides the necessary timing for the Computer Interface to space selective calls between interrogations on the data channel.

CRT OUTPUT interfaces with the Datanet 760 Data Handling program and other system functional programs using the CRT displays. It performs the following functions:

-Displays alarms on the CRT and teletype.

-Displays off-schedule data on the CRT and teletype.

-Displays Demand Interrogation Replies on CRT and teletype.

-Displays Input Error messages and other "canned" messages.

-Records system errors on the teletype.

-Performs CRT screen maintenance.

When this program is turned on, it checks status word and data area for display on the CRT screens and teletype. The CRT screens contain 16 lines. The top line is used for dispatcher interaction with the computer systems and is not numbered. This line is referred to as line 0. The remaining 15 lines are numbered from 1 to 15. Lines 1 and 2 are used for display of alarms. When an alarm is displayed on a line, the line number blinks. Line 3 is used for display of input error messages to the dispatchers. Lines 4 through 15 are used for display of off-schedule data and demand interrogation replies. The program records various messages on the teletype. The messages contain information from the status words and data which requires a hard copy record. Each message is preceded by a time of day printout.

ALARM DRIVER is a software interface between the emergency alarm hardware and the ALARM DECODER program. The driver is entered as a response to a change of state interrupt on a group of 48 digital inputs. This program simply reads the data, stores the data in a buffer and turns on the alarm decoder program. However, since the alarm is sent for a period of time, this driver recognizes that it has received the same alarm within a two minute period and only inputs the alarm once.

Block diagram of monitoring system programs

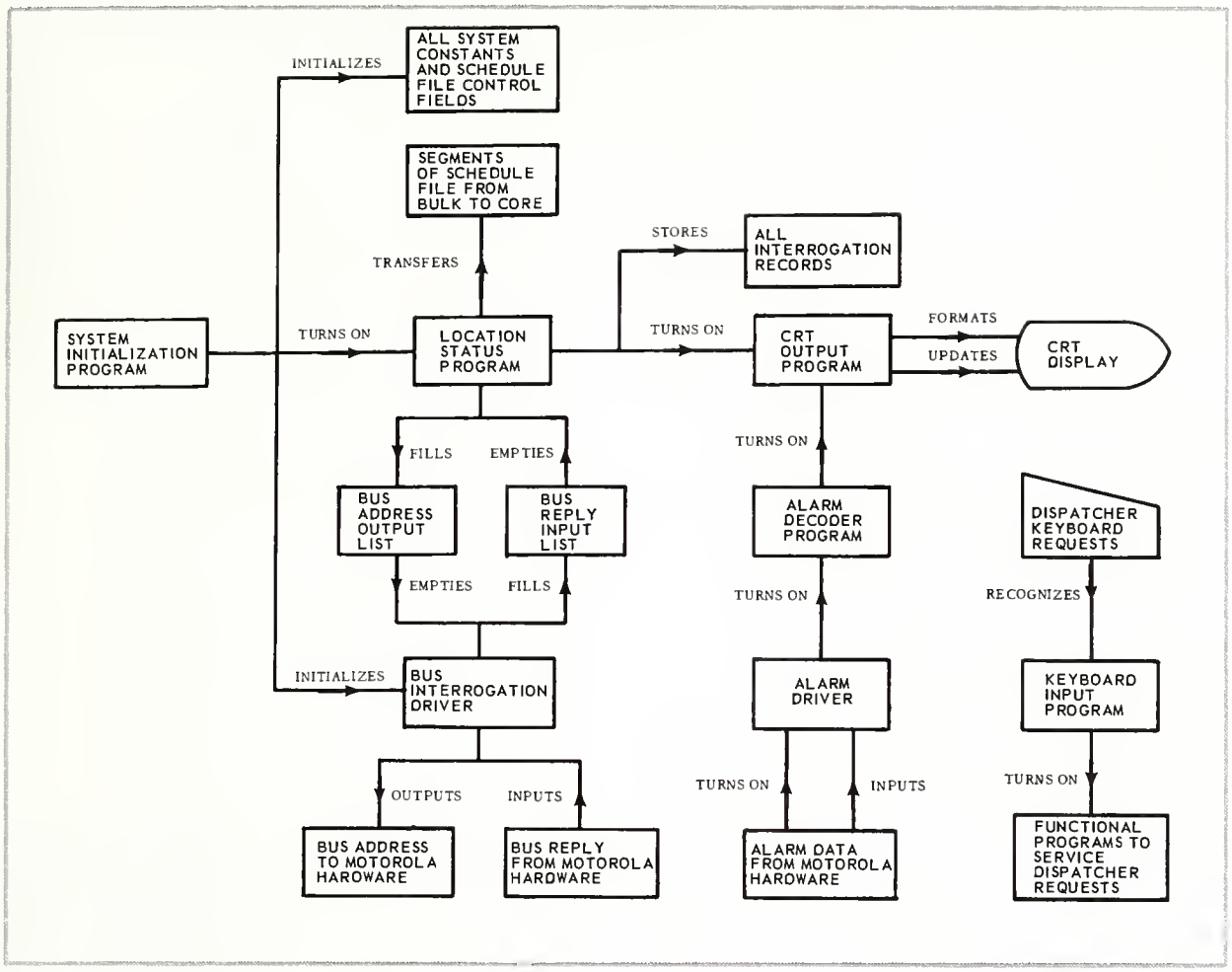


Illustration 30

ALARM DECODER is the highest priority program in the system. It decodes the basic alarm data from the alarm driver as follows:

-Determines the route the alarmed vehicle is operating on.

-Transfers the segment of the schedule file which contains this route from bulk to core.

-It searches this file for the last known status of the vehicle.

-Calculates a distance from the last reported location.

-Stores this refined data in a buffer for the CRT output program.

The CRT output program is turned on with a priority turn-on call. This means that although it is a lower priority program than ALARM DECODER it is turned on as if it were the highest priority program.

KEYBOARD INPUT is the interface between the radio dispatcher and the computer. All dispatcher keyboard requests are serviced by this program. Its basic function is to determine the function requested by the input message and either service the request itself (delete lines) or turn on another functional program. This program can be easily expanded to recognize many dispatcher requests. All requests must be entered on the top line of the display. An acknowledgment that a request has been processed will be made by the CRT Output program displaying a blank line at the top of the display. Additional input requests should not be made until the top line is blank.

Tolerance change services dispatcher requests to change the tolerance (s) (late or early) on a particular route (s).

The program is turned on by the Keyboard Input Program (KBD). It will continuously request data from the dispatcher until he transmits an input buffer containing no data. A permanent record of each tolerance change is made on the teletype.

DEMAND INTERROGATION performs the following functions:

-Interrogates a specific mobile a requested number of times at intervals of approximately 1/2 second.
-Summarizes the results of the interrogations.
-Requests CRT to display these results.

It is turned on by the KBD. Any valid combination of garage - run numbers can be interrogated. When the interrogations are complete, a test summary is displayed on a line of off-schedule data. Additional requests should not be made until the results of the previous test are displayed. Additional test results override the previous results. The results can also be deleted by a normal delete message.

Interrogation software

The block diagram (Illus. 30) may be helpful in following this description of the interaction of the programs during an interrogation cycle. The first program to operate is System Initialization. It initializes all system constants and schedule file control fields. After starting the interrogation driver, it turns on Location - Status.

Location - Status transfers the first two segments of the schedule file from bulk to core and begins searching the schedules for vehicles to be interrogated (i.e., vehicles that are operating or about to begin operation). Whenever it finds a vehicle to be interrogated, it loads the vehicle's address into the address output list.

The Interrogation Driver removes the address from the output list and outputs it to the computer interface equipment. When the reply comes back from the vehicle, the Interrogation driver loads it into the reply input list.

Location - Status removes the reply and compares the location and time information to the schedule. If the vehicle is off-schedule, the appropriate data is stored in the CRT output list and the CRT Output program is turned on.

CRT Output checks all of its input buffers whenever it is turned on. It builds the requested messages in the form needed for output to the CRT and requests the operating system to display them.

Location - Status continues to search all of the schedules for vehicles to interrogate. Once it has checked the entire file, it starts over or delays until it is time to start the next cycle. However, during a cycle, Location - Status is constantly delaying itself. For example, it will load the address output list with 8 addresses and then delay for 250 milliseconds. After the delay, it will process the replies and load the output list with more addresses before delaying again. In this manner, it is never using working core for more than a few milliseconds at a time.

Software alarm

When an emergency alarm is received, the computer is immediately interrupted and the Alarm Driver is entered. This short program reads the data and stores it in a buffer for the Alarm Decoder program which is turned on by the driver.

Alarm Decoder performs the functions as described previously and stores the decoded data in a buffer for the CRT output program which it turns on. Finally, the CRT Output program displays the alarm on the CRT display with a flashing line number to distinguish it from the normal off-schedule alarms.

CHAPTER III
OPERATIONS

Whatever accomplishment Monitor's system engineering represents, the test of the system is in its ability to perform in the real operating environment. This chapter describes CTA's application of Monitor to its bus operations. The utilization of each of the Monitor system's modes--automatic monitoring, alarm, and voice radio--are described in separate sections of the chapter.

SCHEDULE CHECKING

"Where's my bus? Why is it so late?" are examples of questions forming in the minds of passengers waiting in the rain on a cold corner for a delayed city bus. These are questions for which, at the start of this Monitor project, answers were all too often not available anywhere in the supervisory hierarchy of the transit system, at least not soon enough to be of value. After all, how does one locate any vehicle delayed in the choking flow of today's city traffic? What can one do about it even if a bus is found running late? Monitor is the result of an attack on this frustrating problem of transit service through the research and development of a new transit technology.

The goal of this project is to determine whether the nature and extent of bus delays could be learned on a real time basis. Could this information be collected and made available at a well-organized control center? Could potentially substantial delays be detected in an incipient stage, and could remedial action be implemented to cause remission of the problem?

To accomplish these goals, the computerized radio location system of Monitor provides schedule adherence data that would be virtually impossible to obtain by conventional means. Monitor is capable of being expanded to provide schedule adherence surveillance for an entire city bus system. For CTA's 2500 bus fleet, approximately $15 million per year would have to be expended in manpower to approach duplication of the level of supervision that could be given by Monitor at a fraction of that cost.

Off schedule buses appear on the Console's screen

Illustration 1

'Select' display

L
1
2
3
4 602 STOISL M 79-SI 00+ AHEAD
5 581 STOISL M 79-SI 00+ LATE
6 583 STOISL S 79-SI 00+ LATE
7 586 STOISL M 47-KNG 05+ AHEAD
8 588 STOISL M 63-SI 04+ LATE
9 607 STOISL S 93-SI 01 LATE
10 606 STOISL M 79-SI 00+ OVERDUE
11 589 STOISL S 79-SI 01+ LATE
12 605 STOISL S 63-SI 03 LATE
13
14
15

Open mode display

L
1
2
3
4 298 BI E HAR-HAL 02 LATE
5 304 BI W 26-WES 01 AHEAD
6 014 VIM111 S 95-RYN 02 LATE
7 155 SKOKIE E DMP-RT 01 AHEAD
8 012 VIM111 S 111-KED 00+ AHEAD
9 011 VIM111 N 111-KED 01+ LATE
10 000 VIM111 S 95-RYN 01 LATE
11 157 SKOKIE W DMP-RT 07+ LATE
12 146 SKOKIE W DMP-RT 02+ AHEAD
13 013 VIM111 S 103-VIN 04+ LATE
14
15

Illustration 2

With 2500 or more buses in service at once over nearly 150 routes having hundreds of timepoints for schedule control, a large volume of data needed to evaluate performance on a real time basis must be generated. In the Monitor system, this is condensed into manageable form by the computer, whose software is arranged so that only the failure of a bus to adhere to schedule is brought to the attention of a dispatcher.

Monitor has been developed to spot such exceptions quickly; all of the 500 buses now so equipped can be located every two minutes and even with the system expanded to cover 3000 buses, location can be updated every 2½ minutes.

Elements of Monitor

Basic elements of the system include:
-"SIGNPOST" (time point) TRANSMITTERS, presently at 120 strategic locations preferably at route intersections so that they cover more than one bus route.
-BUS RADIOS, each consisting of multi-frequency transmitter-receiver, location memory, electronic timer and vehicle identification.
-RADIO SYSTEM, including transmitters and receivers at strategic locations to insure dependable contact between the control center at the Merchandise Mart and all buses throughout the CTA service area.
-PROCESS COMPUTER, located near the control center, with capacity for storing the schedules, programs and operations performance data of current interest, and for performing comparison calculations and retrieving information from them for display.
-CONTROL CONSOLE, located at the control center, with TV-like cathode ray tube (CRT) displays and controls for the system (Illus. 1).

Bus interrogation cycle

The system is tied together for data and voice communication exchange by its two-way radio equipment. The voice communication linkages are dealt with elsewhere in this chapter. Data communications involved in schedule checking can perhaps best be described by using a hypothetical example.

Let locating run number 098 on the Madison route operating bus number 3160 from garage number 07 (Kedzie) at 0426 hours be this example. Taking into account the size of Chicago's system and its distribution into twelve garages, the combination of run number and garage number are all that are needed to provide discreet identification for schedule comparison purposes.

The Monitor computer is set to interrogate every two minutes all of the runs that its stored schedules indicate to be in service. It finds, at about 0426 that run 098 of garage 07 should be interrogated. Suppose that the bus used in this example is actually passing Hamlin Avenue at the time.

To determine its location, the following has taken place:

-The "signpost" at Madison/Hamlin has been continuously transmitting a repeating distinctive number code with a power so low that it can be received only by buses within a few hundred feet.

-When run 098 passed within range of the Hamlin "signpost," the distinctive Hamlin code received in bus 3160 was stored in its Monitor radio.

-Upon interrogation commanded by the computer, each bus responds only to its own identification. Therefore, when the computer requests report from 07-098, only run 098 out of Kedzie garage can respond, and it does so by transmitting a data code which translated has the meaning "at Madison/Hamlin one minute ago."

-The computer compares this data with its schedule storage. If the bus is on time (or not more than one minute ahead or five minutes late*) the Monitor system takes no further action regarding this run until the next interrogation. If, on the other hand, run 098 was more than one minute ahead or five minutes late,* the computer forms a visual readout message on the control console's CRT display. This takes the form of a line of data showing the run number, the route, the direction, the time point location and the amount of deviation time late or ahead. For example:

098 MAD E MAD-HAM 5 LATE

-Proceeding from the information on the display, the dispatcher investigates and takes corrective action appropriate to the problems, utilizing the voice communication components of the Monitor to talk with bus drivers as well as the conventional supervisory radio and telephone system to bring field supervision, garage assistance or other facilities and services to bear.

Display options

While the normal automatic functioning ("open" mode) of Monitor has been described, the system programming does allow the dispatcher certain options that may help develop clearer definition of a problem.

For example, in the "open" mode, information relating to perhaps a dozen different routes might appear at once on the console display. To concentrate on one route, the dispatcher may switch to the "select" mode in which case only the buses on the selected route will be displayed (Illus. 2).

Another option permits the dispatcher to delete from display any particular line of information. Still another option permits display of information to schedule deviation tolerances other than the normal standards mentioned earlier. This might prove useful to adjust the precision of supervision according to traffic, weather and load conditions, so as to keep the work load for the dispatcher within practical limits.

These options are implemented through a typewriter-like keyboard at the console (Illus. 3).

Achievment of goals confirmed

Experience with this initial generation of Monitor has shown that it can perform all the tasks it was designed to do and that it is capable of a great deal more.

Bear in mind that the schedule adherence function of the Monitor system

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* Literally, one half the scheduled headway (time between successive buses) up to a maximum of five minutes.

Console's keyboard imput

Illustration 3

was originally intended for use solely to identify schedule deviations in excess of a certain tolerance level. It was to gather data from buses throughout the system and present status reports in a form from which assignments to undertake remedial action could be relayed to the existing field supervision force. A conventional transportation operation supervisory force would have carried out their work with the aid of a powerful and sensitive new trouble detection device.

Monitor was also expected to release fixed (point) and mobile (radio car) field supervision forces from the routine schedule adherence ("10 - 50") checks, which now occupy most of their time between actual trouble calls, * and to provide continuous schedule performance monitoring through the voids that now exist between successive "10-50s" on each route. This goal could be reached with an operational, fleet-wide Monitor system.

Goals can be broadened

Experience has also made it evident that Monitor implementation can be made even more effective than the project goals had anticipated. Although looking ahead before the project started it did not seem that it would turn out that way, it now appears likely that the dispatcher at the console will be able to take on part or all of the corrective action once a deviation is reported by Monitor, saving the fixed and mobile field supervision for jobs that would actually require a supervisor's presence "at the scene." After trade-offs in supervisory labor between control center and field supervision, there could be net economies in operating cost, but here again it would appear to be a preferable approach to apply the time freed by the computerized approach toward improving the accuracy of service performance.

Harnessing Monitor's potential

There are obstacles in the way of increasing the dispatcher's supervisory role, but they generally could be solved with additional software. The existing CRT display format was designed to spot deviations. To undertake centralized corrective action effectively another format should be made available.

Information about various runs appear on the screen of the CRT in lines of type that come up in random order. The schedule status of buses on a dozen routes, heading in different directions may be displayed at one time. This format of "open" mode display is simply too confusing for a dispatcher to base effective supervisory decisions on (Illus. 2).

"Debugging" hardware

In the early operational stages, Monitor's problems centered around "debugging" of hardware.

The "bugs" tended to destroy confidence in the system's capability. There were times when dispatchers faced a full screen of apparently off-schedule buses, but in fact the entire display was an electronic fiction caused by equipment malfunctions.

* In a continuing system this time could be saved or used to observe rule adherence, work attitude, or to decrease the levels of tolerance of schedule deviation.

One by one dozens of minor and major technical difficulties were weeded out of the system until today all the hardware is considered operational. CTA has conducted tests in which the Monitor location system proved accurate in locating buses to within two city blocks 84% of the time.

MONITOR ALARM

Should a disturbance or crime be undertaken on a bus there is always a certain risk that any open action of the driver to summon help may actually further endanger his passengers and himself. A goal of Monitor was to develop and test a covert alarm device that, when operated, would cause no visual or audible indication on the bus.

Through Monitor's "silent" alarm device, a call for police help is no farther away than a touch of a button, and in the bus only the driver need know that this has been done (Illus. 4).

Alarm sequence

Depressing momentarily the covert Monitor alarm switch triggers transmission of a code which is translated into a special display at the control center console. This display includes:

-audible tone alarm
-signal light
-digital readout
-flashing CRT display

The digital readout simply translates the transmitted code to show visually for the involved vehicle the garage number, bus number, run number, number of last signpost passed and time (in tenths of minutes) since it was passed (Illus. 5).

Using the same data, the computer develops the CRT display from its stored schedule and signpost references. It converts signpost number into an abbreviation of the names of streets intersecting near the signpost. It converts the time elapsed since passing the signpost into an estimate of the distance (in tenths of miles) from the signpost.

All 'Owl' buses are protected by Monitor — Illustration 4

Alarm digital display

Illustration 5

It also determines the direction in which the bus should be heading. The results of this computer processing are displayed on one of the first two lines of the CRT display. Routine replies to the schedule adherence tasks of the system continue to appear, but on the remainder of the CRT screen.

All these electronic events take place so rapidly that the dispatcher has the processed information in view before the bus driver can release the covert alarm switch.

The dispatcher now can respond to the message by appropriate action including relaying the necessary parts of the message over a "hot line" phone to the police department and to CTA mobile supervisory cars, both of which proceed to the scene.

Even though the bus driver need only touch the alarm switch momentarily, the alarm code broadcast continues repeating itself for two minutes. It can be repeated again whenever desired.

Separate radio channels are available for voice and for data. The channel normally reserved for voice transmission is used for alarm code broadcast and of course that disables its normal function for the two minute period. Preventive circuitry at the bus prevents the dispatcher from initiating a call to it during that time. The bus driver can, however, interrupt the repetition phase for a voice transmission should he consider it advisable to do so. Operating practices require dispatchers to refrain from initiating calls to buses from which alarms have been received until after a field supervisor has been able to contact the bus driver in person. The procedures, which were deemed to be on the safest side in view of the potential problem, could of course be modified should experience so dictate.

Experience with the alarm

Although the 500 Monitor units of the project provided for only a fraction of the CTA bus fleet, this was enough to cover the "owl" (middle of the night) services and they were so deployed, allowing maximum advantage to be taken of the alarm feature.

A test was made over a three-month period under similar service conditions comparing Monitor-equipped buses with non-Monitor-equipped ones. On the non-equipped, 15 incidents yielded three arrests for a 20% apprehension rate. On the equipped buses, six incidents yielded three arrests for a 50% rate. The time elapsed from the start of an incident until the bus driver could get into communication with the dispatcher averaged 8.2 minutes for non-equipped buses. With Monitor-equipped buses, the dispatcher is of course aware instantly when the driver touches the covert switch.

While the amount of data offered is small, the most powerful arguments relating to the alarm are subjective, having more to do with the public's perception of the hazard level on public transit than with the actual level. From this point of view there is absolutely no question that bus Monitor has substantially enhanced driver confidence in his security. There can be little doubt that it can do the same for the public when the equipment is expanded to cover the entire transit network.

Debugging the alarm

Enthusiasm for the Monitor alarm at CTA is not meant to imply that the alarm was free of developmental problems, both technological and institutional. In February of 1972 only 12 out of 629 alarms recorded were legitimate. By October this 2% valid yield was up to 11% (15 valid out of 132). The police department described this reported false alarm level as insignificant, compared to other sources of report. Both technological improvements and revised operating procedures contributed to the reduction in the number ber of false alarms.

A few examples may be of interest:

If an alarm indicates a run number that is not scheduled to be on the street, the CRT display will show no location for the bus. From the digital display the dispatcher finds the bus number and checks whether it is actually at the garage. If so, it is reasonable to assume that the alarm is false and the police are not contacted.

Such alarms are usually set off by a mechanic working near the alarm switch accidentally hitting it. To avoid such incidents the workmen now remove the fuse from the Monitor before working near the switch.

Again, experience showed that most false alarms were accidentally set off by bus drivers and most frequently at relief points or terminals--places where an operator getting in or out of his seat, reaching for his coat or even dropping a lunch pail might activate the covert switch.

Drivers have set off alarms by mistaking the alarm switch for some other switch there was reason to operate.

Accidental driver-initiated alarms were all but eliminated by installing over the covert switch a "protective reminder" spring which makes it unmistakable. It requires that the driver exert pressure and move the spring some distance before he can reach the switch itself, thereby making it less likely to be operated inadvertently.

Drivers are forewarned in training sessions of the possibility of setting off a false alarm. They are instructed to notify the dispatcher immediately should they send an alarm by mistake.

Equipment problems resulted in some false alarms. The primary source of such alarms was a voltage surge overloading the Monitor's voltage regulation system to trip the alarm. This was corrected by a modification to filter out such interference.

Due to inaccurate time information, some difficulty has been experienced in pinpointing the location of a bus when the alarm is activated. The problem was corrected by preventive maintenance procedures that were implemented to increase the reliability of the bus elapsed time generators in the on-bus equipment.

While the problem was being corrected, to catch obvious errors, dispatchers make a quick cross-check of the estimated location of a bus by referring to printed schedules conveniently available to them before contacting the police.

The Monitor alarm system even with its present first-generation equipment, has reached an acceptable level of dependability. CTA is confident that it has reduced the likelihood of incidents occurring on buses.

VOICE COMMUNICATIONS

The use of two-way radio in transit bus operation has today become so commonplace that its need and value can generally be stipulated without lengthy explanation. The brief description of the voice communication component of the Monitor system which follows therefore touches mainly on its more interesting features.

Bus drivers use voice communications to report defects which develop to make their bus inoperable or impair safety, to report service delays, street blockage, accidents, incidents and for other appropriate reasons, the range of which broadens to improve public service as it becomes easier to communicate (Illus. 6).

Without two-way radio, a driver may have to use a pay telephone, if and when he can find one along his route. In a relatively few locations, mostly at terminals, there are available to him private telephones connected into the CTA phone system. Possibly along his way he would be able to talk to a CTA supervisor or someone else who could be of help or at least relay his message.

But with two-way radio, a driver at the wheel of his bus can always be within easy contact of the control center, and through it, within reach of an endless variety of potential services (Illus. 7). Although CTA has used radio for supervisory vehicles since 1939, until the advent of Monitor, it did not seem practical to deal with the message load that ordinary two-way radio would develop working in a fleet of 2500 or more buses.

Features

The voice radio component of the Monitor system operates independently of the schedule adherence elements, but is coordinated with them to enhance its usefulness. One way in which its effectiveness has thus been extended has

Voice communication adds flexibility to Monitor — Illustration 6

Dispatcher at the console Illustration 7

been the incorporation of digital identification. Another is through a selective call function.

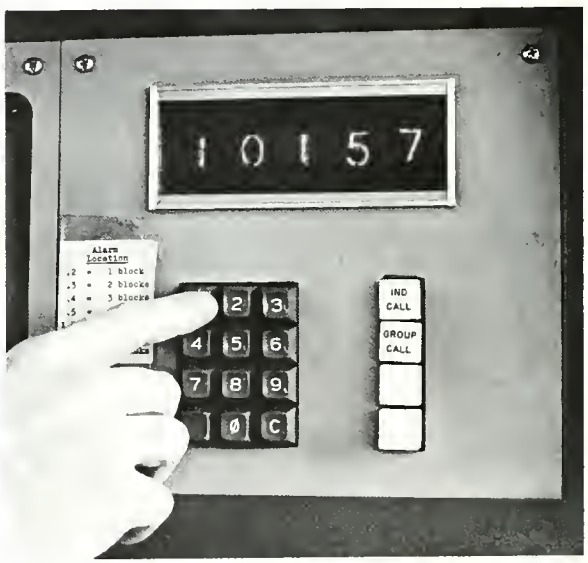
In the Monitor selective call, a dispatcher can reach an individual bus (or, if he prefers, a certain group of buses) by push-button dialing (Illus. 8). This causes a high-pitched tone to sound in the bus called until the handset (like a phone handset, but with press-to-talk switch) is lifted from the hook. Conversation is then carried on with the bus driver with the same degree of privacy as an ordinary phone call.

Call procedure

A driver wishing to initiate a call simply lifts the handset and momentarily depresses the talk button. Within milliseconds, the digital display at the control center console shows the dispatcher the garage number and run number of the bus calling. The dispatcher then responds and the conversation begins. For project accuracy evaluation purposes, these conversations begin with a request for identification of the run calling, but this actually is a repeat of the information available on the display. In an ultimate expansion of Monitor, it could be omitted to make air time available for the increased message load (Illus. 9).

Even now words are kept to a minimum and code words, such as the well known "10-4" acknowledgment, are encouraged. Operators are taught to take time to think through the best and shortest message to convey their request before commencing a call.

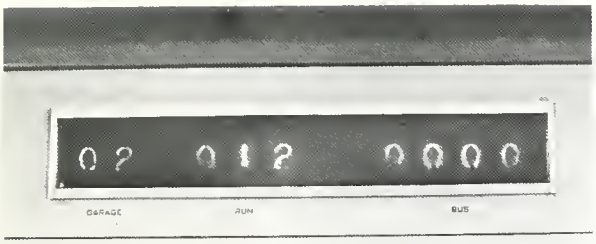
Dispatcher-originated calls are of course a great gain that radio makes over present line wire telephone systems. Inquiries can be made when delays or other problems are detected by (or reported to) the control center. The dispatcher-originated call is currently inhibited by the fact that the project provided equipment for only a fraction of the CTA bus fleet. Since much of the time it is impossible to know which runs have a Monitor-equipped bus, there is on the average less than a one-in-five chance of being able to call a bus.



Dialing a bus Illustration 8

Problems with voice radio

Difficulties with the voice radio portion of the system have been minimal and predominantly related to operational aspects rather than circuit or component failure. The primary problem has been with drivers forgetting to release the handset talk button while waiting for a reply, thus blocking incoming signals.



Digital call identification Illustration 9

Second generation Monitor units can eliminate the problem by taking full advantage of the paired channel nature of the voice radio system. By using both channels simultaneously, it will be possible to send and receive at the same time, and the press-to-talk button will not interfere with the incoming messages.

Absence of an audible signal at the console occasionally results in a dispatcher overlooking an incoming call. The addition of an audible alarm would solve the problem.

Other than correctable minor difficulties mentioned, the Monitor voice communication system has proven itself capable of operating with at least 500 mobile units on a single radio channel.

EMPLOYEE ORIENTATION

Monitor was designed to make the operating employee's life easier and safer. But since it was a revolutionary new system, every attempt was made to insure that our employees were aware of the benefits they could derive from AVM.

Familiarization was chosen as the best way to allay fears drivers might have about automation, computers and AVM. They were shown that the system offered them a number of tangible benefits. The system's advantages to operators were emphasized in a handout pamphlet and a slide show presented at each of the operating stations (Illus. 10). They were:

-Monitor would make the drivers work safer with its silent alarm feature. A driver would never be more than a push of a button from help.

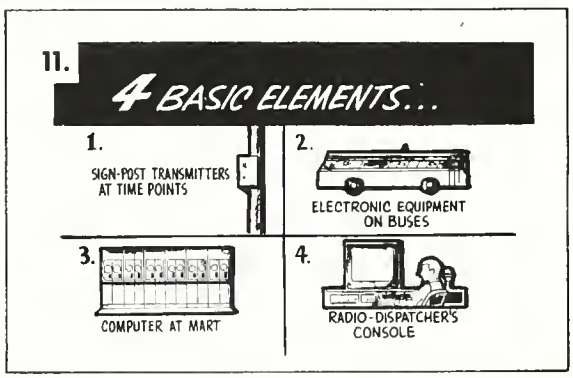
-There would be no need for long walks through rain or snow looking for a pay phone. Monitor's voice radio enabled the operator to alert the dispatcher of breakdowns or other operational problems from the comfort of his bus.

-Better schedule adherence through Monitor would mean each bus driver would carry an even share of the work load.

As a result of the initial informational program, the majority of drivers view it as a tool to make their jobs a little easier.

Training

Three groups of CTA personnel are formally instructed in the operation of the Monitor system on an on going basis; bus operators, dispatchers and repairers. Training programs for all concerned personnel were developed as



Samples from the orientation slide show Illustration 10

part of the demonstration project. The instructions are now included as part of the routine training of all three groups.

Bus drivers

Newly hired bus operators begin their familiarization with the Monitor system during their initial classroom training period. Lecture material on the operation of Monitor is included in two of three bus operator classroom sessions.

The class instruction is followed by live field demonstrations of a bus Monitor unit. At an operating station a CTA instructor shows the beginning operator how to set his run number on the Monitor unit, how to use the emergency alarm, and the proper techniques for sending and receiving messages. The student is allowed to transmit and receive messages during the demonstration.

Each new driver receives a flyer which outlines proper methods for using the radio (Illus. 11). The pamphlet summarizes his instructions and includes a list of "radio shorthand" codes for routing messages such as "10-4" to mean "acknowledge and understood."

Operating proceedures card

EMPLOYES' GUIDE TO USE OF BUS RADIO, EMERGENCY ALARM, AND CODE NUMBERS

GENERAL RULES - BUS RADIO

1. Thumbwheel switches must be set correctly.
   a. Set your run number before leaving the station, when relieving a run, and when trading buses.
   b. Set "000" when cash box is being pulled.
   c. Set "999" when on a charter; also garage personnel making road calls.
2. Master switch or ignition switch must be ON to use the radio or emergency alarm. The bus engine should be running when using the radio.
3. When using the radio:
   a. Pull to the curb or a place of safety; do not use the radio while driving.
   b. When removing the handset from the cradle, always have the push bar released and listen; if the Radio Dispatcher is talking, wait - don't interrupt.
   c. Depress the push-bar to talk; release to listen.
   d. Hold the mouthpiece one inch from your mouth; speak in a normal tone.
   e. Keep messages short and concise; use code number when applicable.
   f. Transmit company business only.
   g. Do not use profanity.
4. When initiating a call:
   a. With the push-bar released, listen a few seconds; if the Radio Dispatcher is not talking, depress and release the push-bar.
   b. After the Radio Dispatcher acknowledges the call, give your bus number, badge number, location and direction, and then your message.
   c. Keep your message short and concise.
5. When answering a call:
   a. With the push-bar released, listen a few seconds; if the Radio Dispatcher is not talking, depress the push-bar, and give your location and direction.
   b. Release the push-bar and listen for the Radio Dispatcher's complete message; do not interrupt.
   c. Make your answer short and concise; use code numbers when applicable.

(OVER)

Illustration 11

Repair staff

Garage instructors and selected repairers receive training in the testing of the bus Monitor units. They are taught how to conduct operational tests of bus radios and to use an electronic test-set.

The training program developed by technical service personnel of CTA and the manufacturer utilizes the lecture-demonstration technique of instruction. Each repairer is expected to perform various diagnostic tests numerous times during his training.

A pamphlet outlining proper diagnostic procedure is distributed to all those involved in the program.

Dispatchers

Familiarization with the Monitor system begins with classroom instruction. Each dispatcher receives four to six hours of lecture material on the system theory and console operating procedures. Two to four hours of demonstration on the console follow the classroom work.

After the formal instruction period is completed each dispatcher begins work on the console under the direction of an instructor. The length of this on-the-job training period varies with the individual.

CHAPTER IV
MAINTENANCE

The millions of parts in the Monitor system are kept in good working order through a carefully designed maintenance program.

The program is divided into two categories. The first is communications maintenance and the second is computer maintenance. The work is contracted with the equipment manufacturers on a fixed cost basis.

Because of the amount of equipment involved (500 bus radios, 120 signposts, base station equipment and satellite receivers) rather complex procedures have been developed to care for the communication equipment. Basically, however, the procedures can be divided into two categories; troubleshooting and repair assignment.

The console

Problems with the control console are detected by observation; alarms and or "ID's" do not decode properly; select calls are not received by known "good radios" or poor audio quality are examples of console problems. These problems are telephoned to the maintenance subcontractor and a technician is sent to repair the equipment.

Programmed analysis

It is possible to plot a reply profile for any route. The summary also includes the number of valid replies, the valid rate

$$\left(\frac{\text{number of valid replies}}{\text{number of replies}} \times 100 \text{ percent}\right),$$

the system rate

$$\left(\frac{\text{number of valid replies}}{\text{number of interrogations}} \times 100 \text{ percent}\right),$$

the number of location changes, the number of replies with no location (signpost 0) and the number of replies with invalid data (separated into random signpost numbers and replies of all ones). This detects runs whose location equipment is not working (large number of no location replies), with high invalid rates (large number of invalid replies) and which do not have a high valid rate (greater than 90 percent).

Buses with a low reply rate, less than 75 percent, and runs that do not reply are then checked for defects in the equipment.

Program improvements

This summary program has been regularly updated and improved. The latest improvement was the addition of a series of indicators showing the condition of the elapsed timer. Each development has improved the overall system performance by reducing the units with specific problems.

The next step will be to link the run number with the bus number used that day. This will be accomplished automatically along with a daily list of defective units and a "card deck" for entry into the maintenance history program (Illus. 2). The listing will then be used to generate repair assignments through the Material Control and Office Procedure Division of the Shops and Equipment Department.

Technician checks Monitor bus radio

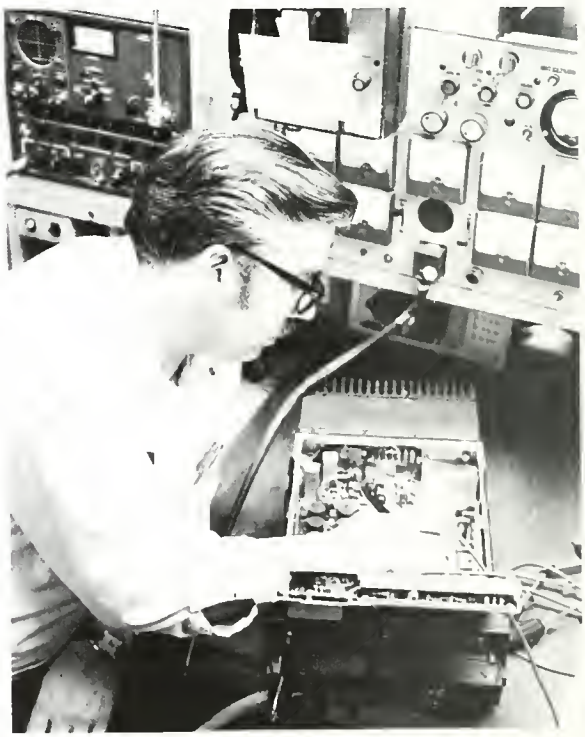


Illustration 1

CTA BUS MONITOR SYSTEM
RUN INTERROGATION SUMMARY

04/12/73 PAGE 1

# OF INTER		REPLY DATA COUNT	CHANGES	VALID DATA COUNT	CHANGES	NO LOC	INVALID DATA ALL ONES	RANDOM	COMMENTS
ARCH 155	GARAGE 5								
216	3/ 1%	2	1/ 0%/ 33%	0	1/ 1	0/ 0	1/ 0/ 0	0	
ARCH 156	GARAGE 5								
205	0/ 0%	0	0/ 0%/ 0%	0	0/ 0	0/ 0	0/ 0/ 0	0	
ARCH 157	GARAGE 5								
207	171/ 83%	9	161/ 78%/ 94%	35	2/ 1	0/ 0	8/ 7/ 1	3	
ARCH 158	GARAGE 5								
183	139/ 76%	12	128/ 70%/ 92%	31	1/ 1	0/ 0	10/ 9/ 1	3	
ARCH 159	GARAGE 5								
156	87/ 55%	14	56/ 35%/ 64%	22	20/ 8	0/ 0	11/ 6/ 1	4	
ARCH 160	GARAGE 5								
137	83/ 61%	14	83/ 61%/100%	28	0/ 0	0/ 0	0/ 0/ 0	3	
ROUTE SUMMARY ARCH									
1095	493	43%	429 39%	88%	24	0	30		
ARH 379	GARAGE 8								
112	105/ 95%	1	100/ 89%/ 94%	14	5/ 2	0/ 0	1/ 1/ 0	4	
ARH 380	GARAGE 8								
82	75/ 91%	3	72/ 88%/ 96%	10	0/ 0	0/ 0	3/ 3/ 0	3	
ROUTE SUMMARY ARH									
194	191	93%	172 86%	95%	5	0	4		
ASH 438	GARAGE 4								
154	79/ 51%	28	70/ 45%/ 89%	21	3/ 0	0/ 0	6/ 6/ 0	3	
ASH 439	GARAGE 4								
156	3/ 2%	2	1/ 1%/ 33%	0	1/ 1	0/ 0	1/ 1/ 0	0	
ASH 440	GARAGE 4								
133	12/ 9%	8	12/ 9%/100%	7	0/ 0	0/ 0	0/ 0/ 0	0	
ASH 298	GARAGE 12								
159	144/ 91%	9	138/ 87%/ 96%	25	2/ 1	0/ 0	4/ 4/ 0	3	
ASH 299	GARAGE 12								
167	156/ 93%	5	107/ 64%/ 69%	25	29/ 1	0/ 0	20/ 4/ 2	4	
ASH 300	GARAGE 12								
155	97/ 61%	26	94/ 60%/ 99%	21	0/ 0	0/ 0	1/ 1/ 0	3	
ROUTE SUMMARY ASH									
928	491	52%	424 45%	86%	35	0	32		

The computer prints out data on the system's performance **Illustration 2**

Through past experience we can request the radio to be removed and sent to the contractor for repair, a technician to come to the garage for on-site repair or repair by CTA personnel. Repairs are keypunched and also entered into the history program.

All the bus interrogation and maintenance data is now being stored for future analysis. It is possible, as experience is accumulated, that new maintenance programming will be developed.

The experience developed relating to repair assignment has minimized the time requirements of the CTA repairmen. Originally, a defective radio was reported and it was up to the repairman to determine the exact nature of the problem using "Bus Repairer's Procedure for Testing Bus Radios." This resulted in excessive time being spent to determine something which was known previously and also resulted in many wrong repair actions taken, the radio being removed when the problem was in the control head.

To insure that everyone involved was aware of his responsibilities, a pamphlet was developed entitled "Radio Maintenance Procedure" defining this activity. This was extremely beneficial from the beginning; however, evolutions in the procedure have not resulted in revisions in the pamphlet.

THE COMPUTER

Preventative computer maintenance consists of regularly scheduled visits by its manufacturer's personnel. They check to see that all mechanical devices are clean and lubricated. Any unusual problems or failures are telephoned into their field engineering office and a technician is immediately dispatched.

CHAPTER V
EVALUATION

The evaluation of the Monitor system is based primarily on tests conducted by the Transportation Systems Center (TSC) of the Department of Transportation and C T A. Each of the tests was designed to provide performance data on critical functions of the system.

Also included in this chapter are sections concerning possible cost benefits derived from the system, radio frequency conservation and public relations benefits.

ORIGINAL GOAL

When the application for Monitor-CTA was first submitted, the goals were stated thusly:

- "To determine the practicability of automatically comparing schedule adherence with a prepared schedule at selected points, including arriving and leaving times at terminals and the display of any exceptions to the schedule beyond an allowable amount at a control center. Automatically checking schedule adherence continuously should substantially improve regularity of service, decrease the number of complaints, and attract new riding."

- "To determine if this type of system could result in more effective use of personnel, less premium time to operators and more efficient utilization of buses."

- "A study and development of a special alarm for extreme emergency such as armed robbery which could be tripped unobtrusively to make available in central control the identification and location of the vehicle affected."

- "To determine if computer analysis provides advantages in daily operation. Since schedule adherence will be a permanent daily record in the computer, it is to be determined if the accuracy of running time can be easily and economically verified, if areas of repeated and excessive delays can be pinpointed for the benefit of all traffic, and if passenger complaints can be cleared more quickly and accurately thus generally improving the public image of mass transportation."

- "To determine if the location and alarm features can substantially increase the number of two-way radio units on a given frequency so as to receive all the advantages of two-way communications without being wasteful of the spectrum."

After the onset of the project, CTA personnel conferred with a consultant to develop a test plan. This plan divided the testing into three categories: technical performance, operational performance and growth potential. Technical performance experiments would evaluate the AVM system equipment and components; tests in this category included: signpost effective range, communication reliability, signpost passing (schedule display) accuracy, location accuracy and equipment reliability.

It was during these development conferences that the evaluation of the system possibly got off the original line of thinking. In viewing the original goals of the system, it can be seen that a system was desired which could provide automatic schedule adherence checking from a central control point. In the TSC evaluation,* it is stated,

> "If the aim of the Monitor-CTA System is to maintain schedule adherence and headway at least as well as a non-monitor system, then from a purely financial point of view, the investment of Government funds is advisable. The cost benefit analysis has shown that mainly with the reduction of supervisors (pointmen and terminal telephone men), the proposed system will pay for itself in the sixth year whether the Monitor System improves schedule adherence or not."

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* Evaluation of the Monitor-CTA Automatic Vehicle Monitoring System.

It is beyond this goal, in the area of improved regularity of service, more effective use of personnel and more efficient utilization of buses, where the testing may have exceeded the goals. As the test plan was developed, it was "obvious" that the system was to provide complete supervision for equipped routes. If a run was displayed ahead or behind schedule, the dispatcher would correct the situation from the control center. This is, and should have been, considered a long term goal of Monitor-CTA, but to attempt immediate operation in this mode was an error of judgment.

In the first place, the programming of the system expected that the dispatcher would take a display of off-schedule information, assign it to "outside" supervision, delete the information from the screen and go to the next display line. He could contact a bus driver to confirm a problem or decide the importance of the problems and which order they should be handled. Before any procedures were implemented, the change in philosophy occurred and the dispatcher was expected to be a centralized supervisor. With the existing open mode display it became obvious that the dispatcher did not have sufficient information to do his job; he needed a "picture" of the troubled route. This resulted in a re-programming to gain the "select" display mode.

TESTING

The delay resulting from the adaptation of the system to its expanded function, compounded by the hardware problems, made it appear that the project might be delayed to the point where no formal evaluation would be undertaken. It was at this time that the services of the Transportation Systems Center (TSC) of the Department of Transportation was called upon to evaluate Monitor-CTA. Starting fresh, TSC organized a new test plan to "(1) determine the technical validity of the existing system and (2) to determine, based on (1) above, if the Government would be justified expending capital grant funds for the completion of the Monitor CTA System." The evaluation was conducted from July, 1972, through mid-August, 1972, utilizing some CTA manpower and much TSC manpower and facilities. The results of these tests were published in a report entitled "Evaluation of the Monitor - CTA AVM System."

Six tests and/or evaluations were conducted: (1) Management and operations evaluation; (2) Schedule and headway adherence tests; and (3) System response rate evaluation; (4) System reliability evaluation; (5) System accuracy (including signpost range) test; and (6) cost benefit evaluation. Generally, the TSC results will be stated with additional comments; interested readers may wish to obtain this report for technical details. Where it is available, CTA gathered material will be inserted.

Signpost range

The signpost range is a factor which directly affects the system accuracy. To the computer, the bus appears to be "at" a signpost from the time it enters the area of influence until 12 seconds after it leaves the area of influence. Once the bus leaves this area, it carries with it an error equal to signpost range divided by average bus speed.

The test

To determine signpost range, an "average" bus was used to take measurements on 72 different signposts; three checks from three different directions (or nine checks) were taken on each signpost.

Each check consisted of approaching a signpost at a slow speed (5 mph), stopping when the signpost signal is received. The range measurement is then made by counting the number of streetlights between the bus and the signpost; multiplying the number of intervals by 85, (the design distance between lights); and adding or subtracting the estimates of the distance from the bus to the street light and the distance from the signpost to its nearest street light.

Besides the signpost transmitter itself, the signpost receiver is a possible source of variance. The different electronic components in individual receivers will cause a small variation in the signal sensitivity; the electronic environment of each individual bus will also effect the sensitivity; and finally, the physical position of the antenna will affect the ultimate signal "capture." Though these factors will vary from bus to bus, once determined, the overall effect will remain constant. To check this effect 32 randomly selected buses were tested against the same signpost. As above, three checks from three directions were taken for each bus.

Finally, the receiver sensitivity is affected instantaneously by the buses environment. Cars, trucks and other buses moving around a signpost will cause the range to vary; their presence will affect the radiation pattern of a signpost and their electrical noise will cause additional interference to the field. This effect was illustrated in all of the tests by differences in the measurements for the same direction.

Signpost range distribution

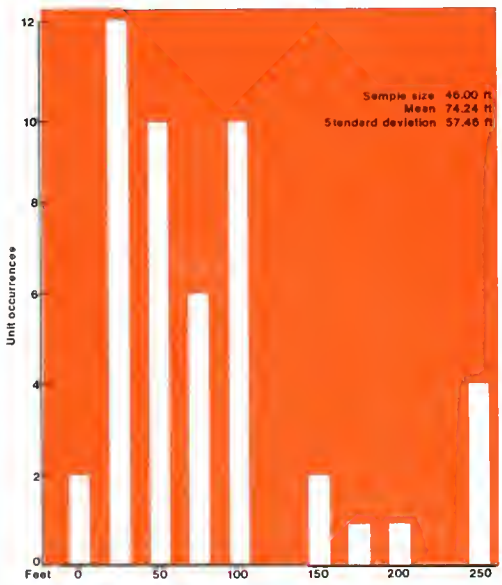


Figure 1

Results

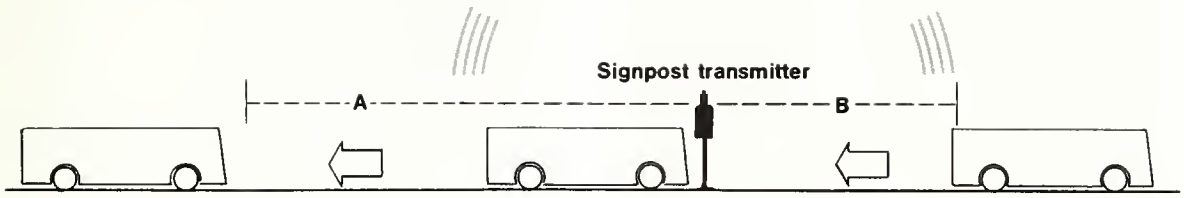
The results of the tests run for TSC showed the maximum (3σ) error for the combined affects is 1460. This is the sum of the transmitter range error, 510 feet; the receiver sensitivity error, 540 feet; and the instantaneous range error; 60 feet. Using the average bus speed of 15 mph, this error equals 98 seconds. The average range of the signposts from the tests was 350 feet or 23 seconds. In calculating the average range error, receiver and instantaneous variances are not considered because they average to zero.

After the tests were completed, CTA was able to go back to all signposts with a newly developed piece of test equipment and adjustment procedure. It was possible to substantially reduce the transmitter power in all cases. After re-adjustment, checks were taken again on 46 signposts (Figure 1). The average range calculated from these tests was 74 feet and the total maximum error was reduced to 773 feet; the corresponding time-errors became 5 seconds and 52 seconds. The reduction in the maximum error does not take into account any reductions in the receiver's variance which logically must have occurred because these tests were not redone.

Location accuracy

When a bus operator sets off the emergency alarm, the bus radio automatically sends his vehicle's garage number, run number, bus number, the number of the last signpost passed and

Effective signpost range



A= area of influence + 12 seconds

B= area of influence

Illustration 1

the elapsed time from that signpost. The computer translates the signpost number into a location name for the signpost while converting the elapsed time into distance from that location. The unit also reviews its schedule files to determine the direction of the bus.

The test

A test was conducted by CTA to compare the calculated location to the actual location

Location accuracy is defined as the actual location minus the computer derived location. The actual location was determined by randomly selecting a run, calling the operator and asking his location; this was then converted to a distance from the last signpost. In reality, the random selection was limited to runs being tracked by the Monitor. The operator was then instructed to activate the alarm for a test and continue in service. The alarm display from the console and the CRT were recorded. In reviewing the data, an error in the programming was detected. This error was later corrected and the data was discarded from evaluation. Similarly, data from faulty equipment was discarded. Fifty-nine checks were performed of which eighteen were discarded.

Results

The results of the checks are shown in Figure 2. Thirty out of the forty-one tests or 73% located the bus within one city block (one-tenth of a mile). Six other tests were within two blocks resulting in 83% of the buses being spotted within 2 blocks or approximately 1000 feet. The average location error was .13 mile or 700 feet. The maximum error (3σ) was calculated to be approximately 2000 feet.

Location error distribution

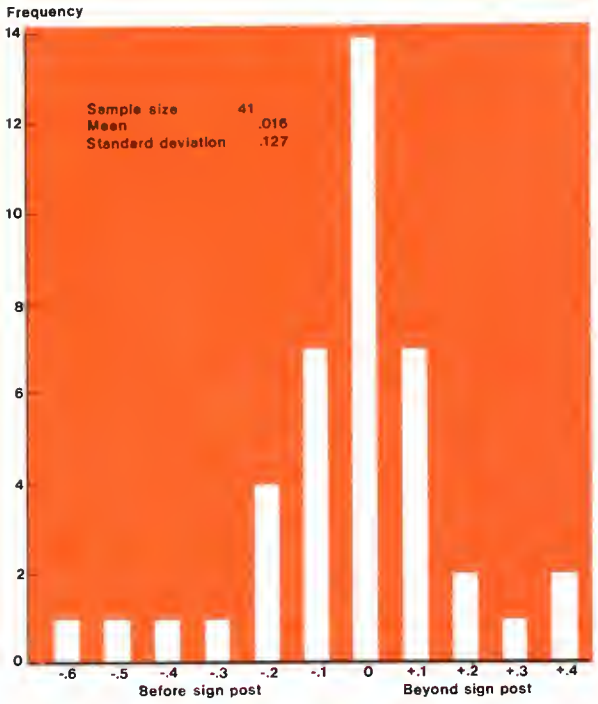


Figure 2

Evaluation

In this test the system proved itself capable of locating a bus within useful tolerances. After the alarm location accuracy tests were completed the signpost range was adjusted (as a result of other tests) to provide more precise location references. Though alarm tests were not conducted with the improved signpost settings, it can logically assumed that the alarm location performance has improved significantly.

Communication reliability

Part of the measure of Monitor's performance is its ability to get replies from the vehicles. Every two minutes, the computer begins interrogating each run in the files one by one; the interrogation is saved for historical analysis along with sufficient identification before schedule checking occurs.

The computer ability to analyze a run's performance is directly related to how that run is replying. If a run replies to every other interrogation, a display may be delayed two minutes waiting for the data to reach the computer. If the reply immediately following an "event" was lost, the computer would have to wait for the next interrogation to find out about it. Another reply mode is where a run stops replying for an indefinite period of time; this may be caused by a poor signal area or an intermittent problem on the bus. This inhibits any displays of the run and with sufficient duration causes a display relating to a signpost to be missed.

The test

An evaluation of the existing system was performed to determine the system valid reply rate, the cause of a low valid reply rate then being experienced and the effect of the reply rate on the system.

The stored data is processed daily and the results are printed. These results are normally used to detect defective bus radios and signposts; they also contain the data which TSC used to evaluate system response.

Station summaries of valid reply rate for owl runs

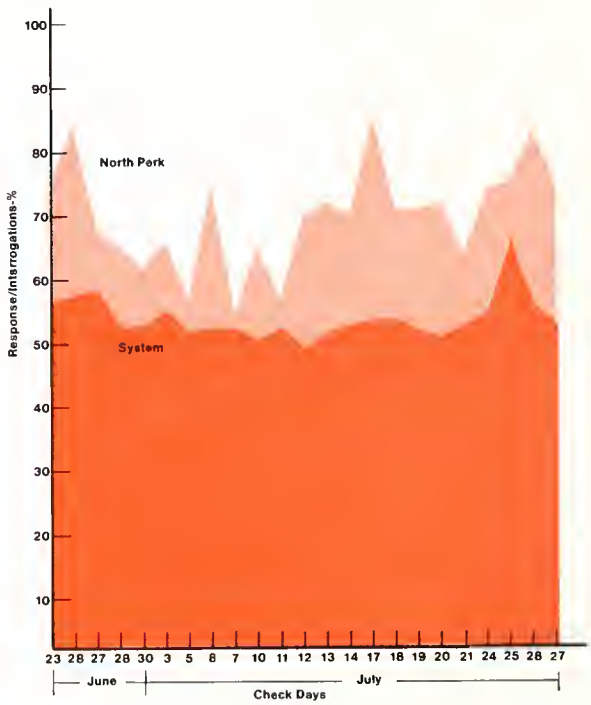


Figure 3

Results

For the period of evaluation (July, 1972) the system valid response rate was found to be 52%. Of the remaining 48%, "no replies" accounted for 42%, and 6% were attributed to "non-valid" replies.

Evaluation

It was theorized that the problem causing these results were:

- -Base station and control center failure
- -Communication blackouts
- -Bus radio failure

Since there was no severe deviation from the mean value, the base station and control center equipment failure possibility was eliminated. This appeared to be a valid assumption; however, after TSC completed their analysis the computer programming was modified and additional data collected. This modification caused the computer to reinterrogate a run if a "no reply" condition was detected; this second interrogation was sent 83 1/3 milliseconds after the first. As a result of this "double interrogation," the system rate was increased approximately 8%. This would indicate a general system problem which was subsequently turned over to the system contractor for study.

In order to analyze the bus radio aspect, statistics were calculated on a sampling of the individual buses. This revealed that radios on 26% of the Monitor equipped buses were inoperative. Our experience suggests that this may have been due to poor maintenance procedures. This can be seen from the interrogation data in Figure 3, particularly for buses from the North Park Station. It would seem that maintenance procedures at the station result in better radio performance. North Park's maintenance program is currently being reviewed for application to our other operating stations.

Part of the problem lies in the area of defect reporting. With only 150 of the 500 units operating nightly, it is sometimes more than a week between "sightings" of a particular bus. This causes difficulty in verification of defects and verification of repair. This results, in many instances, in defective units going out in service, units which do not reply and reduce the reply rate. In a full system deployment this would cease to be a problem since data would be collected on all runs. In addition, further improvements in the computer's maintenance analysis are being planned.

Communication blackouts were responsible for a sizable percentage of the remaining 16% of the no reply responses. In conjunction with this problem, TSC ran a series of propogation tests in Chicago. These tests indicate that average field (r-f) strength is adequate but consists of some very deep nulls where field strength is below that required for operable reception. In areas where no replies are more predominant, these nulls are characteristically wider increasing the possibility of missing an interrogation. This may also be an aspect on which double interrogation has had an affect. While a bus is in a null for the first request, it may travel out of the null in the 83 1/3 milliseconds between requests.

Finally, 6% attributed to non-valid responses were divided into two categories. First, two percent were caused by defective signposts; a signpost sending the wrong number causes the bus to receive the wrong number and reply with a wrong number when interrogated. Second, four percent were caused by bus problems; a defective location receiver and/or decoder would prevent signpost numbers from being stored or other defects would cause the location storage to vary randomly.

Next, a sample of buses was used to determine the average duration of no replies. This analysis (see Figure 4) showed that 33% of the buses could not be controlled at any time due to long

periods of no replies. Forty-nine percent of the buses could be controlled since no replies were limited to bursts of 1 or 2 though displays could be delayed up to 4 minutes). The remaining 18% were subject to episodes during which control was diminished.

Valid response rate

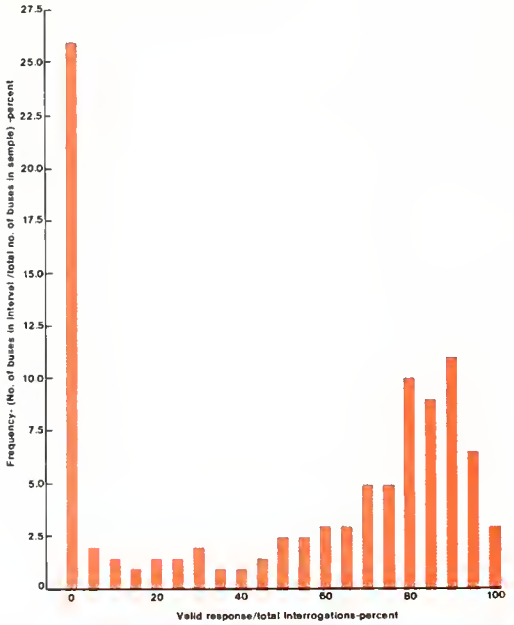


Figure 4

System reply rate

The results of the communication tests caused TSC to delve into the question of the acceptable system reply rate. Rather than determining an absolute number, an analysis was done to estimate an order of magnitude range for the minimum rate. The results of this analysis showed that a system with signposts two miles apart (present system) a 50% valid reply rate is necessary for control of 99% of the buses. If the system were to be modified to one mile signpost spacing (present expectation for total CTA system), the 99% control would require a rate between 80% and 90%.

System accuracy

The time that a bus passes a signpost is the basic element in checking schedule adherence. Therefore, it is essential to know how accurately Monitor can compute when a run was at a signpost. Significant sources of accuracy error were isolated for testing:

Elapsed timer errors are caused by improper operation of the hardware such as the unit failing to reset itself at a signpost, running too fast or slow, or not running at all. Another error is due to the use of a counter; since the timer only counts every twelve seconds, up to a twelve second error can occur. To compensate for this, six seconds is added to the calculated elapsed time except for zero time; any zero time is assumed as at the signpost.

Software errors involve differences between signpost location and timepoint location. Generally signposts are located at timepoints; however, in a few cases to achieve multiple route coverage on a signpost, they were located up to a block away from the timepoint. This causes an early indication in one direction, since the bus passes the signpost before the timepoint, and a late indication in the other. When this situation occurs at a terminal, or when there is no signpost at a terminal, an additional problem is generated. The computer is forced to determine the passing on a signpost which it is presently storing and accumulating elapsed time against. Due to several factors, particularly no replies and defective timers, the computer calculates that the bus has re-passed the signpost before it actually has.

Signpost range errors are discussed in another section of this chapter.

The computer clock error is due to setting the clock incorrectly. If the wall clock is incorrect or the person setting the clock does not enter the time at the proper instant, the clock in the computer, which is the basis for all comparisons, will be incorrect. After the data collection was completed, the wall clock was found to have a +20 second (early) error.

Figure 5 is a summary of the various errors affecting system accuracy. The average error of the known factors is

zero seconds. A test was conducted to estimate the total system accuracy.

The test

The system accuracy is defined as the actual arrival time (at a timepoint) minus the calculated arrival time. The actual time data was collected by schedule checkers at various points recording the arrival time of every passing run. While this manual data was being collected, the computer was monitoring the same runs. The results of the computer determinations were stored on paper tape for comparison to the manual data. The two sources of data were sorted, matched and verified and the system accuracy statistics were generated.

Results

These statistics show that the error range for 95% of the buses was between +3.9 and -2.7 minutes. This is resultant from a +.5 minute mean error and a standard deviation of 1.63 minutes.

Evaluation

Though the exact source of error was not pinpointed, records would indicate one likely source to be defective counters. Within the three months prior to the test, information became readily available to inspect all timers for the first time. This information showed a large number of the timers to be defective. Subsequent investigation by the manufacturer revealed a single component to be at fault in most cases; a new component was selected and a replacement program was begun. This program did not begin until late in June, 1972; therefore, a large number of timers were still defective during the TSC tests.

Software errors also probably caused a significant amount of error in the tests. These problems would be solved

Types of system accuracy error

Type of error	Range of error (sec)		Average or known error (sec)
Elapse time clock			
A. Electronic failure	$-372 \leq \epsilon \leq +372$		Unknown
B. "0" in register	$-12 \leq \epsilon \leq 0$		~ 0
C. Elapse time	$-6 \leq \epsilon \leq +6$		0
Signpost range			
A. Inside range (ave)	$-23 \leq \epsilon \leq +23$		0
B. Outside range (ave)	-23		-23
		Total	-20[1]
Software			
A. Bus direction	Unknown		Unknown
B. Signpost time point	$-20 \leq \epsilon \leq +20$		0
Computer	$-60 \leq \epsilon \leq +60$		$+20$
		Total	0 ± unknown

[1]Assumes that bus is outside of signpost range 90% of time.

Figure 5

System accuracy tolerance

Type of error	"Ideal" range of error (sec)	"Realistic" range of error (sec)
Elapse time clock		
A. Electronic failure	0	$\sim -12 \leq \epsilon \leq +12$
B. "0" in register	$-12 < \epsilon \leq 0$	$-12 < \epsilon \leq 0$
C. Elapse time	$-6 < \epsilon < +6$	$-6 < \epsilon < +6$
Signpost range		
A. Inside range	$-6 \leq \epsilon \leq +6$	$\sim -9 \leq \epsilon \leq +2$[1]
B. Outside range	0	$\sim -15 \leq \epsilon \leq +15$[1]
Software		
A. Bus direction	0	0
B. Signpost time point	0	0
Computer	0	$-10 < \epsilon \leq +10$
Average range	$-6 \leq \epsilon < +6$	$-12 \leq \epsilon < +12$

[1] Assumes that bus is outside of signpost range 90% of time.

Figure 6

once a programmer became available (see recommendations in Chapter 7).

Once the appropriate modifications and corrections are made, the system would be expected to perform within the tolerance recommended in Figure 6.

Schedule and headway adherence

There are various reasons why buses deviate from their normal schedule, but generally they may be divided into two groups. The first group consists of the independent operational variations such as traffic conditions, bad weather, unusual passenger density, fires, accidents, etc. These factors directly affect the operation of at least one bus causing it to run ahead or behind schedule. The second group is the dependent variation which has been given the name "dynamic instability." Failure of a bus to run on schedule causes that bus and other buses to run further and further off schedule (see page 15).

An AVM system theoretically offers a means for controlling the dynamic instability of a bus system by detecting the operational discrepancies caused by the independent variances. Action can then be taken to protect the dependent variances from further disruption through the use of radio communications.

The test

Tests were run by CTA in December, 1971, and January, 1972, and later by TSC in July, 1972, to determine whether a Monitor system improves schedule adherence over a non-Monitor system.

The two sets of tests were conducted basically in the same manner. Data was collected on the selected routes "before" monitoring. Monitoring was then introduced on the route and the corresponding "after" monitoring data was collected. The days on which the data was collected were comparable in

Statistics of test routes

		No. of Signposts	Route Length	No. of Buses AM	PM	Base
#60	Blue Island - 26th	5	15	17	19	10
#28	Stony Island	5	16	28	30	10
#97	Skokie	4	15	12	13	5
#52	Kedzie-California	8	24	26	30	15
#111A	Vincennes - 111th	3	15	15	14	6

Figure 7

weather, passenger, traffic and driving conditions. The same operators were involved with a few possible exceptions. Figure 7 gives the statistics of all the routes selected.

A number of differences did exist between the two tests, however. First, the data collection for the CTA tests was collected over maximum time spans of 30 minutes; whereas, TSC collected data in continuous stretches of three or six hours. Experience has shown that any person checking service at a timepoint will, by his presence alone, start a supervisory action which will rapidly affect the entire route. Drivers who are often tempted to run ahead of schedule will be encouraged to stay closer to the "on time." This will have a tendency to improve the headway allowing operators who are running late to catch up or at least maintain their delay. CTA selected a time span of 30 minutes for checking without seriously biasing the data. The time period was less than the one-way running time but

Schedule adherence Ked/Cal Monitored (Offpeak)

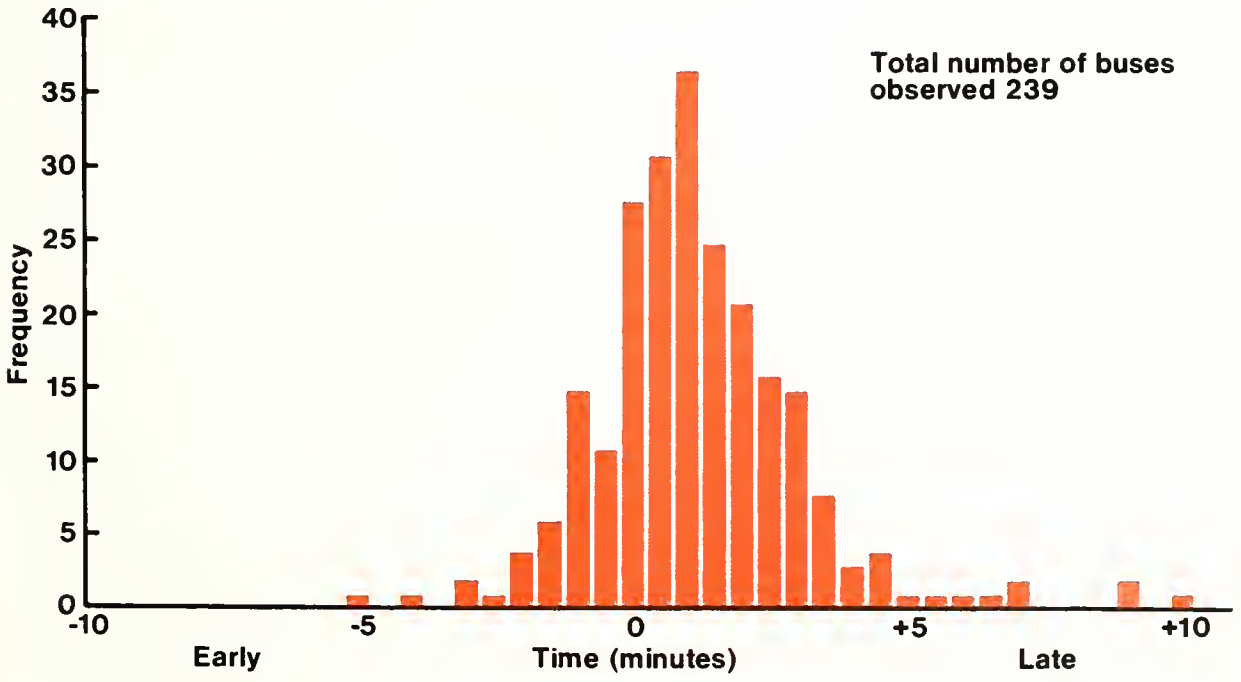


Figure 8

long enough to provide sufficient data.

The second difference was the time of year during which the tests were run. The CTA tests were conducted during December-January when running time allowances are tightest and riding is at a peak. The TSC tests were at a time traffic conditions are optimum and ridership is low due to vacations, no school, etc. These conditions allow the operators to maintain schedule with less difficulty which results in better schedule adherence at all times.

Results

Schedule adherence is the difference between the schedule arrival time and the actual arrival time, whether ahead or late. Mean deviations from schedule were calculated for both before tests and after tests. The results were compared for significance by use of the "two tailed" statistical "T" test. Finally, the percent improvement of the mean and the standard deviations was calculated. The results of these calculations are shown in Figure 9 and a sample of a route histogram is shown in Figure 8.

Evaluation

From the range of the results it is impossible to form an absolute conclusion. However, in the final analysis, one must consider that the dispatchers were never fully trained to operate in the mode expected in these tests; and they were hindered by a significant amount of erroneous information.

TSC next took the data they had collected and calculated the same factors for headway adherence. Here headway deviation was defined as the absolute difference between actual headway and schedule headway. These results are presented in Figure 10. Results of the headway comparisons are somewhat more favorable; however, further improvements should be expected.

Conclusion

The results of the system tests suggest that Monitor may have the potential to perform as well as existing street supervision as a command and control system. Considering today's supervisory labor costs, the savings to be realized from such a performance level are considerable. The future is more promising. We are convinced that with relatively minor effort we can improve the system enough to provide a degree of service dependability through centralized supervision simply not possible with conventional methods.

EQUIPMENT RELIABILITY

Initial analysis of the hardware indicated good reliability in all but one of the individual subsystems, the bus radio. The erratic performance of this important subsystem adversely affected the whole system. A summary of the analysis of the rest of the Monitor system is found in Figure 11. Once the mobile unit was spotted as the primary source of reliability trouble, a more extensive analysis was conducted to gain insight into the problem.

In the investigation of the radio's reliability / maintenance problem, the following factors were given primary consideration:

- -Occurrences of failure
- -Time required to repair
- -Time defective equipment remained in service
- -Loss of effectiveness due to inoperative equipment
- -Environmental effects on equipment

To conduct the analysis data was collected from various CTA sources and the maintenance subcontractor. The data was sorted by bus, bus series (model) and garage. The statistics calculated were based on a 45 day test during July and August of 1972; then to insure against abnormality during this period, records were examined from January to June, 1972.

The statistics derived from this data are depicted in Figures 12 through 15.

Schedule adherence deviation

Time of Day	Route	Test: Non-Monitor $\bar{X}$	Test: Non-Monitor σ	Test: Monitor $\bar{X}$	Test: Monitor σ	% Mean Improvement	% Standard Improvement	Significant ("T" Test)
Composite	Blue Island	2.41	3.13	1.62	2.30	33	26.6	Yes
Peak	Vincennes	2.30	2.55	1.71	1.97	26	20	Yes
	Skokie	1.79	3.15	1.83	2.47	0	25	No
	Ked/Cal	1.79	1.99	2.26	2.36	−26	−20	No
Off Peak	Vincennes	4.23	4.23	3.92	4.52	7	−7	No
	Skokie	2.30	2.96	1.36	1.75	41	43	Yes
	Ked/Cal	1.94	2.10	1.70	1.71	12	19	No

Figure 9

Schedule headway adherence deviation

Time of Day	Route	Non-Monitor (minutes) $\bar{X}$	Non-Monitor (minutes) σ	Monitor (minutes) $\bar{X}$	Monitor (minutes) σ	% Mean Improvement	$\%\sigma$ Improvement	Statistic "T" Test[1] (the monitor test shows significant schedule adherence improvement over non-monitor test
Peak	Vincennes	2.92	2.96	2.26	2.33	+21	+23	yes
	Skokie	2.72	4.10	2.53	3.05	+7	+24	no
	Ked/Cal	2.27	2.49	2.62	2.49	−13	0	no
Off Peak	Vincennes	4.66	4.25	4.23	4.59	+11	+7	no
	Skokie	2.36	2.80	1.87	1.94	+21	+32	no
	Ked/Cal	2.62	2.48	1.96	1.99	+23	+20	yes

[1]The confidence level is 95%.

Figure 10

Subsystem analysis of system reliability

Subsystem	-	Comments
Computer hardware	-	Only 5 or 6 problems have been logged since installation (1-70)
Computer software	-	Existing Programs run reliably; however, modification is recommended
Control consoles	-	Few failures lagged; majority are for failed "Nixie" modules; however, modification is recommended.
Phone line - data modems	-	Initially major source of problem; however, they were corrected and now perform satisfactorily.
Base & satellite equipment	-	Few failures lagged; major problem was lighting. Both satellites replaced but re-installed below top of structure.
Mobile package	-	Poor; text contains detailed analysis
Signposts	-	70 signposts serviced 1-72 through 6-72; however, majority of work was adjustment of r-f power; reliability considered good.

Figure 11

Results

The analysis revealed that the mobile equipment was failing at an unacceptably high rate, with an 80 days MTBF (Mean Time Between Failure). TSC has estimated a desirable MTBF would be in the order of one year. Translated into failure rate, the undesirable rate was 7.1 percent. It is estimated that a four percent rate would be acceptable.

Evaluation

Monitor is a novel system applied to a large scale operation. Routine prototype difficulties were likely to be complicated by large-scale production problems. Although some problems were expected to occur, the overall magnitude of the system component failures was surprising.

With the mobile unit one of the most, if not the most, serious problem was the failure of the logic power supply's main transistor. Physical placement of this component in the unit did not allow sufficient heat dissipation. Continued operation at an excessive temperature caused the device to fail. This factor has been taken into account in the development of future designs. It is difficult to change, however, this component's location in the existing units.

As this was a developmental project both CTA and the manufacturer were prepared to trouble shoot equipment problems. We believe that virtually all the malfunctions encountered with the system have been isolated and corrected.

It should be noted the TSC data in Figure 13 was collected when a failure with the bus mobile unit's interval

Mobile unit reliability summary (During 45 day test period)

I. Failure occurrences	Number of units that failed	Total number of failures
1. Number of units that failed one time	173	173
2. Number of units that failed two times	44	88
3. Number of units that failed three times	4	8
4. Number of units that failed four times	2	4
5. Total number of units that failed	223	
6. Total number of failures		281
7. Average number of unit failures per day (281 ÷ 45)		6.24 units/day
8. Average time between failure (24 ÷ 6.24)		3.84 hours/unit
9. Average time between failure of an individual unit (3.84 X 500 ÷ 24)		80 days
II. Bus population		
1. Average number of units in shop per day (see Fig. 14)		35.5 units
2. Total number of buses which carry mobile units		500
3. Average % of bus population with mobile units in shop		7.1%
III. Other		
1. Average time to get defective unit off street into shop		4.8 days
2. Average shop time to repair a defective unit		6.0 days

Figure 12

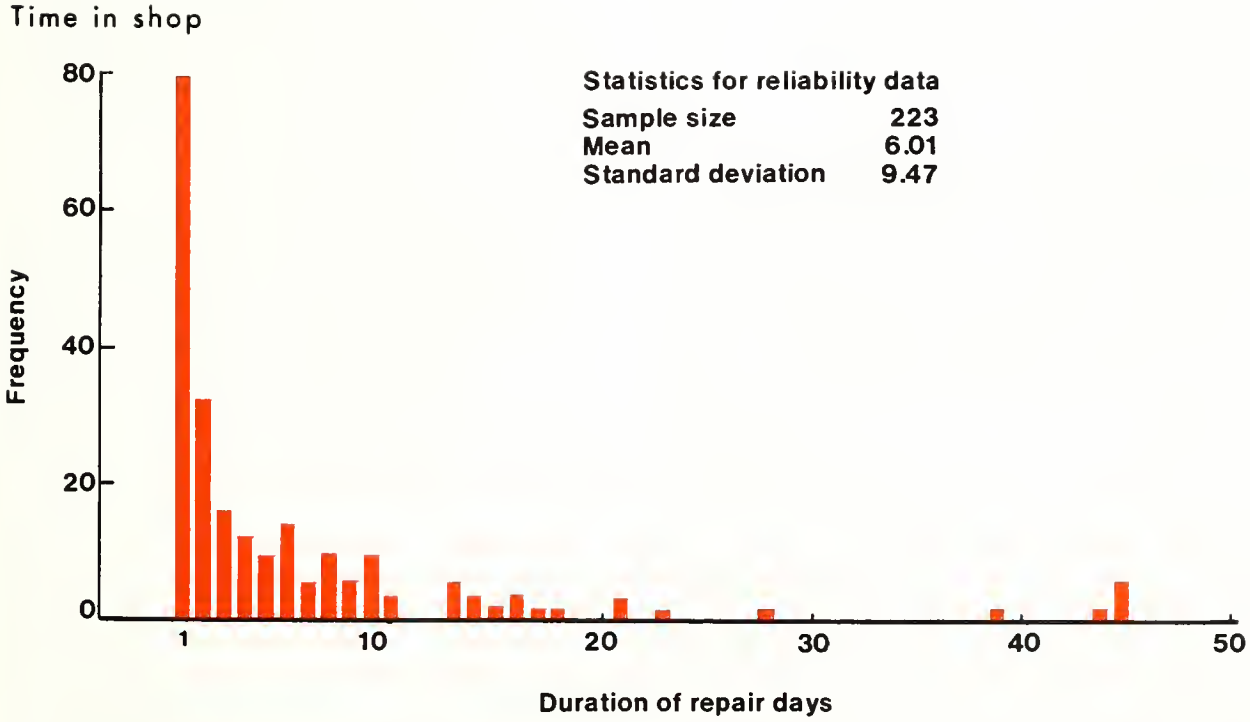


Figure 13

Equipment in shop by day

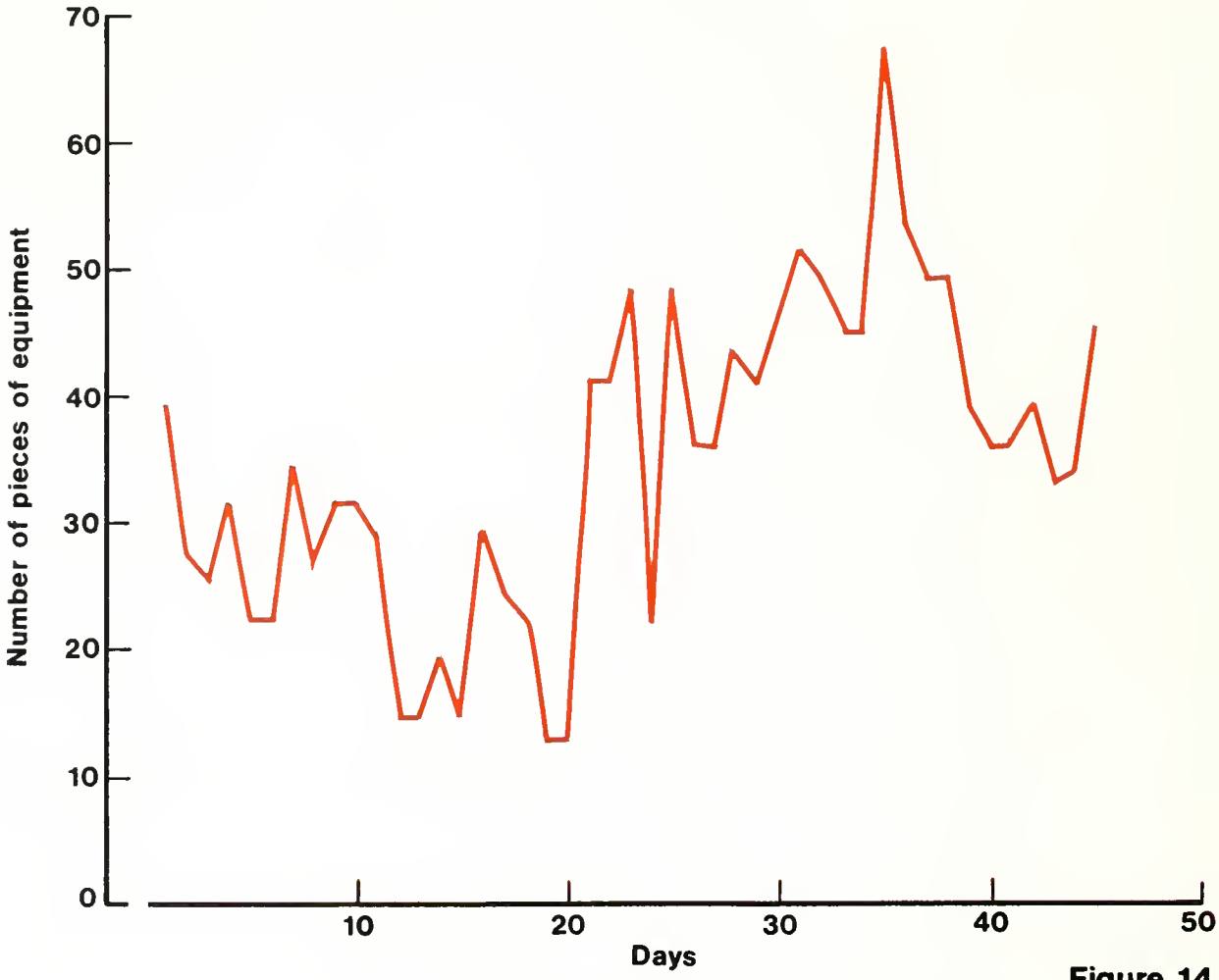


Figure 14

Failure record - January thru June

	Failures	Days	Daily Average
January	172	25	6.88
February	147	23	6.3
March	29	11	2.6
April	69	23	3.0
May	60	20	3.0
June	95	21	4.5
Test Period June 27 - August 10	281	45	6.24
Totals	853	168	5.12

Figure 15

timers was being corrected. While the problems had already been isolated and a solution developed, the radios were held in the shops for extended periods awaiting new parts. Taking this factor into consideration the average time in shop for repairs could be reduced from 6.01 to 4.48 days.

There have been the usual problems with developing the maintenance procedures for a new system. For example, there was some difficulty in ascertaining which unit of the mobile was causing a problem, the main package, the control head, intercabling, etc. In many cases, the radio (main package) was sent to the repair shop though the problem was in the control head. The shop would find the radio satisfactory, return it to the garage, and it would be reinstalled. Next time the bus went out the same problem would be detected and reported. Besides reducing the system reliability, this generates more defect reports than really exist. Accurate detection and repair of defects reduce the number of failures by an estimated 25%.

There is a need to speed up the methods used to get a unit to a repair facility and fix it. When a defect is spotted, the following steps must be taken to get a radio into the shop. The bus number must be matched to the run with the noted defect. Next, the defect is reported to the Shops and Equipment Department coordinator who oversees activity of all garages. This group notifies the individual garage of the defect. The garage then arranges to bring the bus in for repair and notifies the coordinator when the bus is available.

Since a defective radio does not affect the operation of a bus, the bus will be used in service until a defect is reported; therefore, a bus might be "on the street" when the report is received. When the bus returns to the garage, it is finally put aside for repair. The coordinator then notifies the shop to pick up/repair the radio. These procedures are currently undergoing scrutiny to improve the performance.

When the entire CTA fleet is Monitor equipped, another aspect of the maintenance will improve. Because only a portion of the Authority's buses are currently Monitor equipped, not all bus repairers have been instructed in maintenance procedures. If these men are involved with other tasks the radios may not be attended to. In a full system environment this would not be a problem since all personnel would know the procedures.

COST EVALUATION

For cost evaluation purposes, Monitor - CTA has to be considered as two distinct systems: first, a two-way radio system and secondly, an automatic location system.

Voice radio

The benefits of two-way voice radio systems had been well established before the Monitor - CTA demonstration project began. CTA was already operating a two - way system on its rapid transit while other transit systems had radio equipped bus fleets. In fact, CTA had made a decision independent of the development of Monitor to equip its fleet with two-way radio.

Location system

The TSC report indicates that the initial capital investment for CTA's 2,700 bus fleet of $3,349,130 over the cost of standard two-way radio could be saved in five and one - half years of Monitor operation (Figure 16). The savings are based primarily on a projected reduction in the level of supervisory costs. (See Figures 17 and 18).

The TSC report states, "...that this represents a conservative estimate of the value of savings due to the assumptions that (1) no reduction in the number of buses or operators would result and

Discounted present value of savings (cumulative)

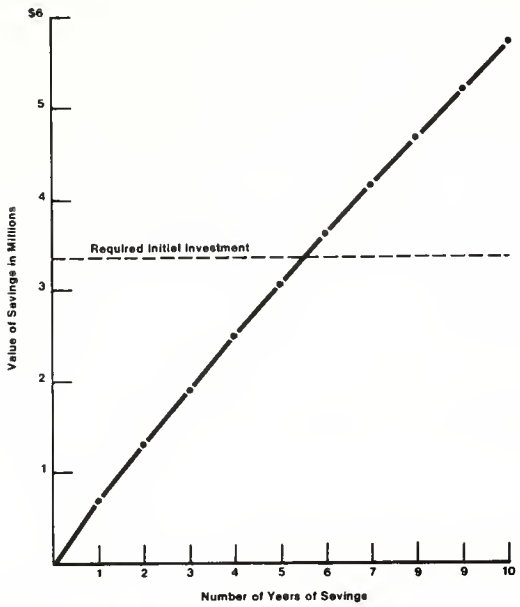


Figure 16

(2) all AVM compatible radios (which are each $325 more expensive than standard radios) would be purchased over a period of several years, the present value of this differential cost would be reduced, increasing the present value of the savings."

We fully expect that there will be improvements in schedule adherence when the system is fully installed. Just how dramatic those improvements might be is difficult to estimate at this point. But even minor reductions in deviation and the resulting decrease in vehicle and labor costs can bring about large monetary savings.

An AVM system operating in Hamburg, Germany has resulted in four percent reduction in fleet size. The system is similar to CTA's though not as sophisticated.

If we make the conservative assumption that our more sophisticated system will make it possible for CTA to reduce fleet size by two and one-half percent as opposed to Hamburg's four percent reduction it can be seen that 67 of the Authority's 2,700 buses could be eliminated. Based on annual operating costs of $30,000 per vehicle the total annual savings from even a small improvement in schedule adherence would amount to $2,100,000.

Transit consultants in this country have indicated CTA might realistically expect that the Monitor system would allow the Authority to reduce its fleet size on the order of four percent.*

Conclusion

In summary, the cost of the Monitor system may easily be justified even if it results in no overall improvement in schedule adherence. Even minor improvements in schedule adherence, and the resulting reductions in fleet size made possible would add dramatic additional cost benefits.

The TSC report concludes, "...from a purely financial viewpoint, the proposed AVM system represents a good investment."

* Mitre Corporation report for the Urban Mass Transportation Administration, September of 1971.

Non-recurring costs

Radios for 2,700 buses at $475 each	$1,282,500
500 signpost transmitters at $475 each	237,500
Base equipment for two data channels	25,000
Control center equipment (consoles)	650,000
Control center equipment (computer)	350,000
Installation of above equipment	153,000
Differential cost for 2,000 Monitor compatible radios of $325 per unit	650,000
Training of 10 new radio operators at $113 per man	1,130
Total	$3,349,130

Figure 17

Recurring costs

Item	Current Annual Cost	Durotian
Maintenance of communicotion equipment and signposts	$ 60,000	10 years
Maintenance of computer	12,000	10 years
System manager	20,000	10 years
Two system onolysts/programmers	32,478	10 years
One pragrammer far first five years	15,436	5 years
One system maintenance coordinator/system engineer	15,436	10 years
Ten additional radio operators at $18,800 each	188,000	10 years
Additianal troining for radio operatars - two per year at $113 each	226	10 years
Fifty fewer supervisors (point men and terminal telephane men) at $17,125 each	(856,750)[1]	10 years
Four fewer schedule clerks at $17,135 each	(68,540)	10 years
Two fewer typists at $11,416 each	(22,832)	10 years
Reduction in annual overtime charges	(8,000)	10 years
Elimination of annual street telephone charges	(32,640)	10 years
Elimination of annual terminal reporting telephane charges	(12,914)	10 years

[1]Parentheses indicate cost reduction.

Figure 18

FREQUENCY CONSERVATION

The Monitor-CTA system is designed to ascertain the location of vehicles throughout the city, provide two-way voice communications between the dispatcher and all vehicles and allow transmission of an emergency alarm to the dispatcher from the vehicles.

Selection of the r-f (Radio Frequency) channels for transmitting the data and voice information is a very important aspect of this system. Basically, three types of channels exist in this system. 1. Voice Frequencies 2. Data Frequencies 3. Signposts Location Frequencies.

Voice frequencies

Frequencies in the 450 MHz band are used for voice communication. This band was chosen on the basis of frequency availability and technical superiority. There were virtually no 150 mc frequencies available, and insufficient 50 MHz frequencies for a final system. Also, the urban operating environment would cause a severe noise problem if a 50 MHz band were used.

The additional frequencies were made available at that time as a result of an action by the FCC to "split" (reduce the band width requirements) of the 450-470 MHz band. This will provide sufficient channels for full implementation of this system. The CTA is licensable as a local government agency.

As established by FCC regulations, the voice channel operates on a 2-frequency basis--one frequency for base station talkout, and a second frequency for mobile talk-back. On this basis, two frequencies in the 450 MHz band were required for voice communications in the pilot system.

Data frequencies

From the point of view of economics, it was desirable to use the same radio equipment in the bus for both the voice and data channels, and to simply select the appropriate frequency as the unit is used in each communications mode. This means that the data frequencies also had to be on the 450 MHz band.

Two frequencies are required for data, one for interrogation and one for reply.

Signpost location frequencies

The signpost location transmitters operate on continuous duty, with a short transmission range. Several frequency bands are possible candidates for such operation. A frequency in the range of 100-200 MHz appeared to be technically feasible; however, the high noise level in the downtown areas seriously hampered the use of this band. A frequency in the 72 MHz band might have been satisfactory, but use of this band may interfere with television reception in some parts of the city.

As a result, a 153.7325 to 153.7475 MHz splinter frequency band was chosen for the signpost transmitter. This frequency is desirable from a technical point of view, as well as being economically feasible due to readily available equipment in that band.

Radio frequency interference

A question which might arise in the selection of frequencies relates to r-f interference. During their propogation tests, TSC also measured adjacent channel interference. The results of these tests were "...no harmful interference was experienced even while situated in the proximity of the AVM transmitter. It is further stated that where equipment is operated in the central business district the channel characterization... reveals no special problems for the CTA AVM system but the large random Multipath delay scatter will present an interesting challenge to future high data rate systems."

Final system

The final system will operate in the same frequency bands that are used in the pilot system. In the case of the signpost transmitters, no additional frequencies are required. In the case of the data channels, one additional frequency for interrogation and one for reply is required, making a total of four data frequencies in the final system.

The number of voice frequencies required in the final system will be twelve --six for base station talkout and six for mobile talk-back.

In a normal voice communications system the FCC rules grant one pair of frequencies for every 100 to 200 vehicles. An example of this is the Memphis Transit System and the Dallas Transit System who have 300 to 400 buses, respectively in operation and both are operating with two voice channels (Figure 19).

If CTA were to equip its entire fleet of 2500 buses for voice communication only, with a conventional system between 12 and 20 channels would be needed to operate efficiently. CTA is presently licensed for six pairs of frequencies for voice operation, one frequency for the signposts and one data channel. Equipping the 2500 buses for full AVM would require only one additional data channel.

With Monitor it may be possible to operate up to 500 buses on only one voice channel. Therefore, with Monitor CTA equipment in all our buses, we could realize a saving of 4 to 12 pair of r-f channels, or 50 percent of the channels required for voice operation.

The current Federal Communications Commission (FCC) Rules and Regulations do not provide for regularized licensing of vehicle-location systems. Rather, it is necessary to operate on a developmental basis. As the benefits and needs for this type of system become more apparent, especially from a spectrum-efficiency point of view, it is expected that regularized licensing will be permitted.

The use of systems such as Monitor-CTA can contribute to efficient use of the spectrum in several important ways.

1. A large part of voice-radio communications in a practical operating system is for the purpose of establishing location of the vehicle.* An automatic-location sys-

*Figure 19 shows that 75% of a typical day's radio messages in Dallas and Memphis relate to bus schedule operations.

Radio utilization by the Dallas and Memphis transit systems

MEMPHIS TRANSIT SYSTEM		DALLAS TRANSIT SYSTEM	
300 Buses 2 Channels 450 Mhz 2 Dispatchers		400 Buses 2 Channels 150 Mhz 2 Dispatchers	
In and Out Garage	855		
Start Run Report	636		
Supervisors Report	100	Radio calls pertaining to scheduled adherence	1,555
Misc. Calls	493	Misc. Calls	520
Total Daily	2,084*	Total Daily	2,075*

Approximately 75% of radio calls pertain to schedule adherence. 25% are miscellaneous.
*An analysis of radio messages for a typical day's operation.

Figure 19

tem, using data techniques, can accomplish this function more efficiently.

2. Some of the other types of information such as identification, alarms, odometer readings, etc., can be transmitted more efficiently in data form than in voice form.

PUBLIC RELATIONS

Monitor-CTA cannot help but have a positive effect on the public's view of CTA. As a successful system it offers them a number of tangible benefits:

- -Better schedule adherence.
- -Control of transfer meets.
- -Shorter delays.
- -Improved passenger security and peace of mind.
- -Immediate attention and assistance for ill passengers.

In other words Monitor leads to a better quality of service for our patrons. It is logical to assume that service improvements have a positive effect on patronage.

A 1967 survey conducted in the Chicago area lends support to the assumption. In-the-home interviews were conducted with 381 bus riders and 75 people who never ride buses.*

The following information was derived from the survey results.

Of the 75 non-riders, 21 suggested that they might ride buses if changes could be incorporated into the existing system. Of these 21 who suggested they might become riders, nine (43%) indicated that improved scheduling, additional buses or less waiting for buses was an area they desired improved. It appears from the above that improved schedule adherence, as intended through bus AVM techniques, could entice some, if not a sizeable percentage, or non-riders in Cook County to ride buses.

People who already ride buses might be induced to make some more use of the bus system. Of the 381 bus riders surveyed, 75 (19.7%) said that they would ride more if the existing system could be improved. Scheduling was the area most often suggested for improvement, by a margin of more than two-to-one over any other area.

* Conducted by R. H. Bruskin Associates for the Transit Advertising Association.

CHAPTER VI
COSTS

The costs incurred by the demonstration project were charged against a revised budget of $2,310,860. This chapter contains the charges against the budget and a breakdown of the purchase price of the system.

In addition to the actual project costs an estimate of the cost to expand the pilot project to the full CTA system is given. This should be of interest to prospective AVM users as a projection of the expected cost of the individual system components is included.

Detail of system cost

Purchase of 500 bus radios at $1,890 each	$ 945,000
Purchase of 120 signpost transmitters at $317 each	38,040
Purchase of 2 control consoles at $51,000 each (including control center electronic logic)	102,000
Purchase of fixed radio equipment (base stations, satellite receivers and voting equipment)	22,350
Rental of computer for 2 years (including maintenance)	139,572
Maintenance of system for 2 years (including initial adjustment)	125,400
Total price of system	$1,372,362

Figure 1

Detail of capital investment

Purchase of bus equipment	$ 945,000
Purchase of signpost transmitters	38,040
Purchase of fixed equipment	22,256
Purchase of control center equipment	102,000
Installation of bus radios	130,350
Installation of signposts	9,529
Installation of fixed equipment	6,131
Installation of control center equipment (including computer)	16,380
Other purchase costs	245,760
Total capital investment	$1,515,446

Figure 2

Final project cost statement

Item	Revised Budget Approved April 6, 1973		Accumulated Costs April 1, 1968 to September 30, 1972 Total[1]
Staff Salaries		$ 92,000.00	$ 91,852.15
Employee Benefits		23,000.00	22,963.06
Travel		1,530.00	1,527.84
Construction or Rental Contracts		165,000.00	162,389.17
Install Equipment - Buses	$ 132,939.00		130,350.18
Install Equipment - General Office	16,400.00		16,379.57
Install Equipment - Wayside Beacons	9,530.00		9,528.51
Install Equipment - Communications	6,131.00		6,130.91
Consultant Contracts		115,688.00	90,777.43
Institute of Public Administration	86,988.00		85,000.00
Data Analysis	16,700.00		4,188.77
Final and Progressive Reports	12,000.00		1,588.66
Other Project Costs		1,894,385.00	1,834,312.95
Communication Equipment - Buses	1,197,375.00		1,181,249.99
Wayside Beacons	47,550.00		47,550.00
Data and Voice Communications	22,300.00		22,256.29
Display Equipment	102,000.00		102,000.00
Maintenance	183,140.00		183,135.25
Computer	196,500.00		194,801.46
Programming	36,100.00		29,551.30
Operation	95,420.00		70,405.28
Marketing	4,000.00		3,363.38
Printing Final Report	10,000.00		—
Sub-Total		2,291,603.00	2,203,822.60
Contingencies		19,257.00	1,442.59
Total Project Cost		$2,310,860.00	$2,205,265.19[2]

[1] 79.50% of the project cost was funded by the U.S. Department of Transportation, the remaining 20.50% of the cost provided by CTA.

[2] Subject to minor revisions including the addition of final report preparation cost.

Figure 3

Cost of implementing Monitor for 100% of CTA

Mobile equipment		
Replacement of original 500 radios		
Material	$ 250 per bus	
Labor	350 " "	
	$ 600	$ 300,000
Retrofit new buses to full monitor (1070 buses)		
Material	$ 256 per bus	
Labor	48 " "	
	$ 304	325,000
Purchase of radios to complete fleet[1]		
Material	$3000 per bus (700 radios)	
Labor	400 " "	
	$3400	2,380,000
Wayside equipment - signposts		
Purchase of 400 (maximum number) signposts		
Material	$ 550 ea.	
Labor	50 "	
	$ 600	240,000
Fixed radio equipment		
Purchase of equipment for 5 voice channels[2]		
Material	$ 60k ea.	
Labor	5k "	
	$ 65k	325,000
Purchase of equipment for 1 data channel[2]		
Material	$ 100k	
Labor	5k	
	$ 105k	105,000
Control center equipment		
Purchase of 10 control consoles[3]		
Material	$ 20k ea.	
Labor	1k "	
Engineering	2k "	
	$ 23k ea. + 20k	250,000
Purchase of computer equipment[4]		
Material	$ 400k	
Labor	25k	
Programming	105k	
	530k	530,000
		4,455,000[5]
Contingencies		545,000[6]
		$5,000,000

[1] Expects 300 bus w/monitor order in FY 74
[2] Includes voting, line conditioning, and decoding equipment and installation of telephone lines
[3] Desk, display and control only; the exact number of consoles is to be determined, this is an approximate number; includes 1 man-yr. of engineering; includes modification of the operations control center
[4] Includes 4 man-yrs. of programming and administration; includes modification of the data center; does not include back up computer
[5] Includes more recent cost estimates and labor items not included in TSC estimate in Chap. V
[6] Contingencies not in TSC

Figure 4

CHAPTER VII
THE FUTURE

As a result of this project we are convinced that a vehicle monitoring system is a valuable tool for the improvement of service. We believe that Monitor - CTA is capable of meeting virtually all current and projected requirements for an AVM system, and it is operational today. Therefore, the Authority is recommending a three-year program to develop and expand Monitor - CTA to all bus operations.

THREE PHASE EXPANSION PROGRAM

The expansion of the Monitor system would be conducted in three phases, thereby minimizing the financial burden and adjustment problems involved.

Phase I
Equip all buses

The first year's efforts would involve the expansion of the bus radio fleet and the voice radio system. The entire CTA fleet would be equipped. This should not only provide a better communication system but it should simplify the assignment of buses.

With the demonstration fleet of 500 equipped buses, it was difficult to schedule Monitor equipped buses to be on specific streets at specific times so the system could function effectively. If the entire fleet was equipped, the question of placing Monitor buses properly no longer would exist.

As part of the expansion program, the Phase I radios, those purchased for the demonstration project, would be replaced gradually so as not to interfere with operations. These radios have a poor maintenance record as described in Chapter VI, due to the developmental problems. It is expected that reliability of the equipment would be improved in future purchases of Monitor equipment by the inclusion of a clause in the specifications requiring a MTBF (Mean time between failure) of at least one year under penalty of a continuing full-warranty.

Possible expanded console

Of course, it would be impossible to have all bus radios on one channel. As more radios are added, more base stations transmitters and receivers would be required. This equipment would be in proportion to the number of radios purchased.

Phase II
Equip all routes

The second year of the planned expansion would include the installation of about 380 additional signposts to cover the remainder of the bus routes. A plan for placement would be developed which would optimize the distribution of all of the signposts. This can be accomplished with little change in operations; as the signposts are installed, the computer files and tables would be modified to identify them.

Phase I and II
Concurrent CTA efforts

During the first two years of the three year program, the computer programming would undergo revisions necessary to improve the display system. Operating procedures would be studied and revised to improve dispatcher performance. The dispatchers would be individually instructed with a program designed to build their confidence in the system and develop their job dexterity.

The Monitor system is presently implemented to cover "owl" service on 60 routes. During Phases I and II, no routes would be added to the system. Thus, the route capacity would remain constant while allowing the dispatchers to develop their expertise on a small system. As the proportion of Monitor buses on these routes increased, and the dispatchers became more adroit, the stage would be set to expand these routes to 24 hour coverage.

Phase III
Total fleet monitoring

The third and final stage of the expansion would include the control center and the remaining bus operations. While Monitor - CTA serves well in its originally specified role as an information gathering system, if it is to be used for dynamic control, the control center will have to be expanded. This would be scheduled for the third year to allow sufficient time to improve the display format and operations. Also, the operational experience accumulated during the first two years of the program would be utilized in the redesign of the control console as recommended in the TSC Report. The full system control center would then be constructed.

To accomplish this undertaking, a group of people would be assigned the responsibility of implementing the above plan. They will coordinate the installation and updating of the bus equipment, develop the signpost location plan, perform the signpost location plan, perform the computer program revisions, revise the procedures and assist in the training, and provide the plans for the system control center. The addition of technical personnel is recommended by TSC. They also will be responsible for the continuing maintenance of both the system hardware and software.

This group could also provide for the evaluation and implementation of Monitor related ideas which have been or will be suggested. These ideas already include hardware systems such as passenger counters, "start trip" indicators, engine status indicators, odometers and fare box alarms. Other ideas for software systems might include programs to assist the dispatcher in restoring service, such as on-line simulations and turn-back calculations, or performing normal tasks, such as automated logging and bus ordering.

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